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SOME FACTORS RELATING TO THE PHYSIOLOGY OF EARLINESS IN CABBAGE, LETTUCE AND TOMATO.

by

© Bernardo Augusto Badani

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ABSTRACT

The early maturity of vegetable cultivars is of utmost importance in northern areas where the growing season is very short.

Although studies concerning the physiology of seed germination, of physiology of flowering and of fruit pre and post harvest physiology have been numerous little research has been done in relation to the physiology of vegetative earliness.

The purpose of this study was to provide an approach to the understanding or measuring of this physiological phenomenon determining some of the factors that might influence it and that might provide a basis for future research work.

Three vegetable crops, cabbage, lettuce and tomato were grown at the Parkland Farm and the Plant Science Greenhouses of the University of Alberta during the years 1972 and 1973.

The percentages of phosphorus and calcium in dry leaf tissues and the shoot:root ratio of these crops were determined and net assimilation measurements were conducted for tomato and cabbage.

Statistically significant negative correlations were obtained between % phosphorus in dry leaf tissues and days to maturity of the lettuce cultivars. No significant correlations were obtained in the tomato and cabbage studies.

Significant positive correlations between % calcium in dry leaf tissues and days to maturity were found for cabbage and lettuce. No consistant correlations were obtained for tomatoes.

Significant positive correlations were obtained between shoot:root ratio and days to maturity for the three species studied.

The limited data obtained for net assimilation studies could not be analyzed statistically but they did suggest some interesting hypotheses.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

In Edmonton and similar areas where there are only 100 days frost free periods to grow crops, the early maturity of cultivars is of utmost importance in the failure or success expected in their production.

Early maturity provides an economic advantage to the farmer in allowing him to market his produce early. It also enables the vegetable industry as a whole to have fresh, locally produced vegetables for a longer period of time. This can be a great advantage, specially if we consider that in Alberta we import fresh vegetables most of the year at a value in excess of $10 million per year (3). Even a two week extension of the market could account for a very large quantity of money that could remain in the country.

Studies of the physiology of seed germination, of flowering, of fruit ripening and of post harvest physiology have been numerous but very little has been done in relation to the physiology of vegetative earliness.

Experiments conducted by M.L. Pandita (52) on the relationship of vegetative earliness to % P content, % dry matter, chlorophyl content and malic acid content of leaf tissues and by S.A. Molnar (47) on the evaluation of pH, total sugars and relative amounts of malate and citrate as a criteria for earliness in tomatoes have opened the way in this area. However, very little is known about what factor or factors could be used as an index to determine the maturity period of a certain cultivar without the need to grow it to maturity; a lengthly and expensive process.

If an index or criteria could be found that would eliminate the necessity of "growing on" plants considerable savings in money and time might be achieved.

Furthermore, if a factor or combination of factors could be definitely correlated to early maturity, investigators in that area might make use of a better knowledge of the physiological and/or genetic bases of earliness in initiating breeding programs to improve such earliness.

What factor or factors could be considered? Reference has been made to a few that have been considered in previous studies by several authors but undoubtedly several others might provide a better approach.

Thus, the purpose of this study has been to find criteria that, at the early stages of development, could be correlated to earliness and to determine some of the factors that affect these criteria.

A study that would provide an horticultural, practical approach to understanding or measuring these physiological phenomena might be of interest to future researchers.

Three vegetable crops, Tomato (*Lycopersicon esculentum* L.), Cabbage (*Brassica oleracea* var. *capitata* L.) and Lettuce (*Lactuca sativa* var. *capitata* L.) were used as the test crops in the investigations.

The relationship of four factors to the vegetative earliness of these crops was considered. The four factors were: percentage of phosphorus and percentage of calcium in dry leaf tissue, shoot:root ratios and net assimilation.

LITERATURE REVIEW

A. The Role of Phosphorus in Higher Plants and Its Relationship to Earliness

I) The Importance of Phosphorus in Plant Nutrition.

Phosphorus is one of the main elements needed for plant growth and development. Although the modern phosphate fertilizer industry did not start until 1840 when Liebig demonstrated that the fertilizer value of bones could be increased by treating them with sulfuric acid, its use in the natural form such as bone or guano goes back to prehistoric times and has been practically world wide.

It is generally considered that plants take up most of their phosphorus as the primary orthophosphate ion $H_2PO_4^-$ and in smaller amounts, as $HPO_4^=$. Other forms of phosphorus such as metaphosphates, pyrophosphates and certain soluble organic phosphates such as phytin or nucleic acid may also be absorbed by plants but their relative importance under normal conditions is practically negligible when compared to the orthophosphate ions.

The effects of an adequate phosphorus level in higher plants are multiple. Historically an increase in root growth, development and proliferation has been associated with it.

Experiments conducted by Tatsumi and Kageyama (71) on tomato seedlings have shown that phosphorus promoted new root development especially when phosphorus had been a limiting factor. Foliar phosphorus sprays influenced the ability of developing shoots to absorb other nutrients, particularly at the early stages.

Experiments by other authors (19, 75) have reinforced this assertion.

The effect of phosphorus on the development of the aerial part of the plant has also been extensively studied. Cutcliffe and his associates (20) working on the effects of several nutrients on broccoli plants have shown that a good phosphorus supply increases the terminal (central inflorescence) and the lateral (axillary stalk) growth. Increases in yield, earliness and phosphorus content in tissue samples were also observed during their experiment. D. Oprea (50) in experiments conducted on grape vines observed that phosphorus deficiency was responsible for a decrease in the stem diameter, in the wood/pith ratio, in the number of hard phloem layers, in the amount of phloem in the vessels and the starch supply.

Another effect associated with adequate phosphorus fertilization is an increase in yields. Khupse and Kalke (36) working on cabbage plants have shown that a direct result of increased phosphorus levels was an increase in head weight, dry matter content and total yield per acre. Similar results were observed in beans by Mascarenhas and his associates in Brazil (40).

Finally a good supply of phosphorus has been shown to hasten maturity, as will be reported in more detail, in a later section of this review of literature.

II) The Role of Phosphorus in Plant Metabolism

Phosphate metabolism in plants includes three distinct phases (75). The first phase involves the absorption of inorganic phosphates and their combination with organic molecules or radicals. In the second phase these primarily phosphorylated compounds transfer the phosphoryl group to other molecules. This step is known as transphosphorylation. In the

third and final phase phosphate or pyrophosphate is split from the phosphorylated intermediates either by substitution of an organic radical or by hydrolytic cleavage.

The oxidative-reduction potential energy set free in oxidative metabolism is the main source of energy for the incorporation of phosphate into organic combinations.

The potential energy that can be released by the energy rich phosphate bonds gives phosphorus the key role it has in plant metabolic reactions where the phosphorylated compounds such as ATP can act as energy carriers.

Phosphorylation (39) is the biochemical process by which phosphate or phosphoryl radicals are transported, by a transfer reaction, to an acceptor, increasing the reactivity of the compound, lowering the energy barriers and overcoming otherwise unfavorable thermodynamic conditions.

The role of these compounds in glycolysis, Krebs cycle and certain aspects of photosynthesis is very well known and as early as 1952 an excellent review dealing with this matter was written by Harry G. Albaum (2).

Phosphorus also has a key role in the synthesis of nucleic acids and in the interconversion of sugars.

The availability of phosphofructokinase and ATP seems to be a factor of major importance in carbohydrate metabolism.

The importance of the exchange of phosphate between ATP and inorganic pyrophosphate in the synthesis of proteins could be described, according to G.C. Webster (82) by the following schematic process.

Step 1 Amino Acid Activation

$$AA + sRNA + ATP \overset{Mg^{++}}{\rightleftarrows} AA - sRNA + AMP + Pyrophosphate$$

Step 2 Peptide bond formation

$$n(AA - sRNA) + Ribosome \overset{GTP}{\rightleftarrows} Polypeptide\ attached\ to\ Ribosome + ns RNA$$

Step 3 Release of polipeptide from ribosome

$$Polypeptide\ attached\ to\ ribosome \xrightarrow{ATP\ Mg^{++}} Polypeptide + Ribosome$$

Finally phosphorus is a constituent not only of the sugar phosphates and phospholipids but also of nucleic acids, nucleotides, phytic acid and certain coenzymes (21) all of which are needed for plant growth and development.

III) Effects of Physiological Age and Translocation on Phosphorus Levels of Higher Plants.

Phosphorus (unlike calcium, manganese or boron) is readily redistributed within the plant. During periods of phosphorus deficiency a large proportion of the phosphorus available in older leaves may move to other more actively growing areas such as meristematic tissues in younger plants or, at a later stage, to fruits and seeds where a large proportion of the phosphorus in mature plants is located, becoming accumulated there during their development (43). Studies with radioactive phosphorus as early as 1940 (4) have shown additional evidence of the high mobility of this

element. Thus, physiological age does have a marked influence on the accumulation levels and phosphorus requirements of different tissues.

B.T. Cooil and associates (18) in experiments conducted in Macadamia trees in Hawaii have shown that the influence of phosphorus availability on vegetative growth is only important in young plants while at later stages its effect is limited to the yield of nuts produced.

Similar effects were observed in tomato plants by Arnon and Hoagland (5). Plants first were grown for five weeks at adequate phosphorus levels. When phosphorus was later excluded from the nutrient solution a detrimental effect on the vegetative growth was only observed when the plants were allowed to flower and fruit normally since to be able to supply these highly active organs with adequate P levels, a redistribution, even from the younger vegetative tissues towards these organs had to take place within the plant. When plants were deflowered this redistribution was not necessary and a normal vegetative growth was observed.

IV) Relationship Between Soil Nutrients and Phosphorus Levels in Plant Tissues

The total amount of phosphorus in plant tissues is directly dependent, on availability in the nutrient solution (17). Experiments conducted on strawberries by Roberts and Kenworthy (60) have also confirmed this fact.

However the level of other nutrients in the soil solution can also have a definite effect on phosphorus uptake by the plant. The relationship between phosphorus and nitrogen has been extensively studied. Although generally it has been reported (1, 35) that an increase

in nitrogen levels in the soil solution produces a decrease in the phosphorus content of plant tissue, this effect appears to be dependent on the source of nitrogen used.

While this previous assertion is true for NO_3-N, experiments conducted by C.R. Blatt (10) on 'Acadia' strawberries and by Horada and associates on young plants of several species (32) indicate that NH_4-N has rather the opposite effect, i.e. increasing phosphorus uptake by the plant. Increases in phosphorus levels in the nutrient solution however, have always resulted in increases in the nitrogen levels of plant tissues. This increased nitrogen has been reported by Yuda and Okamoto (85) to be mainly as protein in in leaf tissue of citrus plants, and by J.N. Davies (20) as nitrate in the tomato fruit.

The ratio of N to P has been found to be a better index for determining fertilizer requirements than the actual levels of these nutrients present in tissue analysis, considered independently (22,38).

Srivastava and Agrawal (68) in a study of the fertilization of sugar cane have shown that the level of P_2O_5 present in the soil nutrient solution is critical if heavy applications of nitrogen are applied.

Calcium and magnesium also have a marked influence on phosphorus uptake due to the effect that soil pH has on the availability of this nutrient in solution. At low pH values and on soils high in aluminun and iron, phosphates are rendered less available due to their reaction with these elements. The addition of a liming agent will inactivate the aluminum and iron ions, thus increasing the level of available phosphorus. However, if liming is continued to a point where soil pH increases much over the 7.0 pH level phosphorus availability will decrease once more due to the precipitation of it as calcium or magnesium phosphates (75).

The aluminum:phosphorus ratio is very important in the uptake of phosphorus (64) due to the binding effect of the aluminum ion.

An increase in cobalt (6) and boron (49) levels in the soil solution has been shown to have a positive effect on phosphorus uptake by the plant and on the levels present in leaf tissue.

Generally adequate levels of all plant nutrients are directly or indirectly required for a normal phosphorus uptake and turnover by the plant since plants suffering from deficiency or toxicity symptoms of any nutrient are bound to have a general imbalance in their metabolic activities and thus will affect the presence of phosphorus in tissues.

V) Other Factors Affecting Phosphorus Levels in Plant Tissue

Other factors also have an important effect on the uptake of phosphorus.

Low osmotic potentials have been shown to decrease the phosphorus uptake by beetroots in a study conducted by Resnick and Flowers (58) in 1971.

Soil moisture also has a direct influence on phosphorus uptake. R.M. Thorup (74) measured the phosphorus uptake by tomato plants under controlled soil moisture conditions. Decreases in soil moisture levels produced a marked decrease in phosphorus uptake by the plants. Wilson, (84) in experiments done on one month old *Trifolium subterraneum* plants at different levels of moisture depletion showed that the amount of acid soluble phosphorus compounds decreased markedly when the relative turgidity was low. Decreases of 50% or more were found in most phosphorus compounds in wilted plants in which relative turgidity was 20-45%. Large decreases in the concentration of these compounds were

also found at levels of 70% relative turgidity while a rapid increase in concentration was observed when plants recovered full turgidity under proper moisture levels.

Soil temperature has a marked effect on phosphorus absorption. Carter and Lathwell (17) on experiments conducted on excised corn roots have reported that the Q_{10} of the orthophosphate absorption is approximately 2, that is that for every 10C increase in temperature approximately twice the amount of orthophosphate is absorbed by the roots.

The use of growth regulators has also been reported to affect phosphorus content in plant tissues. Generally higher amounts of phosphorus in tissues and a faster uptake of this nutrient have been reported by authors working with these substances (16, 34, 51). However Fedorov (23) working on apples and golden currant cuttings reported that IAA and 2,4-D applications inhibited the absorption of phosphorus by these species.

Carbon dioxide enrichment of the atmosphere has been reported by E.T. McEvoy (42) to increase the rate of uptake of phosphorus in chrysanthemums, geraniums, and cucumbers at ranges between 500 and 1500 ppm of carbon dioxide concentrations.

Finally some other factors such as air temperature and light conditions may also affect phosphorus uptake mainly through their effects on plant growth and metabolic activities.

VI) The Relationship of Phosphorus Uptake and Content in Plant Tissues to Earliness

Phosphorus fertilization has been claimed to be responsible for hastening maturity. In experiments done on tomato plants in Bologna, Italy, (26) increases in phosphorus fertilization were shown to increase

the size of the fruits and to hasten maturity. Similar results were obtained by J.S. Brar and associates (12) working on the same species.

According to A.L. Sommer (66) the effect of phosphorus on maturity is probably due to the increase in growth that higher levels of this nutrient can promote, growth that allows the plant to take up other ions at a faster rate. These ions may thus become limiting factors responsible for the hastening in maturity.

M.L. Pandita (53) in experiments conducted at the University of Alberta on tomato, radish, cabbage and lettuce plants found that a correlation existed between total phosphorus present in leaf tissue samples and days to maturity. Studies were conducted on cultivars of these crops with different maturity periods. With each of these four crops a significant correlation was found at some stage of growth between earliness and phosphorus content in leaf tissue samples. Correlations were greater at the earlier stages of plant growth. For cabbage and radish this correlation was found to be positive whereas for tomatoes and lettuce the correlations were found to be negative.

He tentatively concluded that in the case where positive correlations were found, a higher phosphorus level in plant tissues might help in hastening physiological processes, but no possible explanation, with the data available, could be given for the negative correlations although the possibility of these results being dependent on genetic factors was mentioned.

Later experiments conducted by E.B. Casement have indicated considerable variation in such correlations relating to cultivars (personal communication).

B. The Role of Calcium in Higher Plants and Its Relationship to Earliness.

I) The Importance of Calcium in Plant Nutrition

Calcium is an element required by all higher plants.

Its uptake is in the form of Ca^{++} ion which takes place mainly from the soil solution and probably, to a lesser extent, by the process of contact exchange (75).

Calcium is necessary for root elongation. Ekdahl, as reviewed by Brayer and Stout (14) found in studies conducted on the roots of wheat plants that in the presence of calcium salts six times the elongation of root hairs is produced. This was attributed mainly to the effects of calcium on pH.

H. Sorokin and A.L. Sommer (67) have shown that calcium is necessary for the continued growth of apical meristems in *Pisum sativum* roots where, in the absence of calcium, mitotic divisions become aberrant or suppressed.

High external calcium levels have been reported by H.E. Street (69) to cause stunting of root hair growth presumably by hardening the growing tip.

Studies done by Barke and Menary (7) on tomato plants where calcium deficiency was induced through the use of ammonium salts, determined that calcium deficiency may cause Pith Rot. Foliar sprays of calcium were found to offset yield reductions resulting from moderate fertilizing with $(NH_4)_2 SO_4$. High total calcium in the plant was directly related to a marked decrease in fruit yields.

Y. Miura (45) reported that increasing levels of calcium in the nutrient solution decrease general growth and make the leaves leathery

in appearance in studies conducted on *Cyclamen persicum* plants.

These apparent contradictions on the enhancing or inhibiting effect of calcium on plant growth and particularly on root growth might be explained in the light of evidence obtained by A. Wallace (80) that calcium is needed only in trace amounts by higher plants, whereas the usual large levels utilized may primarily only detoxify other elements. Bush beans grew very well when calcium content of leaf tissue was only 210 ppm and that of the root tissue 350 ppm (on a dry weight basis). To obtain normal plants at very low levels of calcium in the nutrient solution it was necessary to reduce the levels of other cations such as iron, magnesium and copper since they were otherwise toxic.

Another effect of calcium on plant growth is to reduce the incidence of some physiological disorders such as Pith Rot and Blossom End Rot (B.E.R.). C.R. Millikan and associates (45) found that on tomato plants B.E.R. incidence decreases with the presence of higher levels of calcium and that the K:Ca ratio was higher in fruits affected by this physiological disease.

The main effects of calcium are probably due to its effect on the soil pH. The value of liming has been known from antiquity. The early dwellers of Aegina applied marl, soft unconsolidated deposits of calcium carbonate, to their land and the Romans, who learned its use from the Greeks and Gauls even classified the various liming materials. Columella and Pliny made recommendations for its use.

The indirect benefits that calcium thus provides are multiple (75).

The availability of microelements, with the exception of molybdenum increases with a decrease in the soil pH value and this can have serious consequences due to the toxic nature of many of these elements at anything other than minute concentrations. Aluminum and manganese solubility

increases with a decrease in soil pH and this, in addition to its toxic effects, can interfere with the adsorption of magnesium and other basic cations including calcium itself. Molybdenum deficiencies are related to low pH values in the soil.

Detrimental effects on nitrification also take place at low pH values and liming with calcium salts can counteract this effect especially since most of the organisms involved in the nitrification of ammonia require large amounts of active calcium.

Decomposition of plant residues and breakdown of organic matter is also reduced in acid soils. Nitrogen fixation, both symbiotic and non-symbiotic is also affected in acid soils. Calcium salt, by raising the pH values of the soil can exercise a favorable effect on all these phenomena.

Finally the structure of fine textured soils may also be improved by liming due mainly to an increase in the organic matter content and, to a lesser extent, to the floculation of calcium saturated colloids (75).

II) The Role of Calcium in Plant Composition and Metabolism

Calcium is found in abundant quantities in leaf tissues where solid deposits of calcium oxalate and even calcium carbonate are sometimes found along the vascular bundles of these organs. Sulfate and phosphate ions probably also contribute insoluble calcium salts in some cases. However much of this element is found in plants in the vascular sap where it often precipitates as crystals of calcium oxalate. Calcium is also found in the cell walls where it is believed to form relatively insoluble salts by reacting with pectic acids in the middle lamella. These calcium pectates are generally accepted to act as cement between the adjacent

primary walls so that the cells of a tissue remain bound to one another.

According to Salisbury and Ross (63) this could explain why calcium deficiencies cause a marked inhibition of bud development and death of root tips since cell division is most active in these meristematic areas. The cell plate that divides two daughter cells is rich in pectic substances and under normal circumstances it would become the cell lamella. Perhaps, these authors advance, calcium performs an essential function in its synthesis and stability.

In higher plants at least, calcium is needed in low concentrations in membranes to maintain their proper structure and differential permeability characteristics.

Calcium also forms salts with other organic acids and may enter into combination with protein molecules.

It is possibly involved in binding the R.N.A. to the protein in the chromosome and its defficiency can cause chromosome fragility (21).

Calcium is also known to have a role in the nitrogen metabolism of plants and appears to be important in the reduction of nitrates in plant tissues (44).

Calcium is an essential part of the ∝amylase enzyme, that is directly involved in starch digestions and calcium is also required as a cofactor by some other enzymes involved in the hydrolysis of ATP and phospholipids.

Finally there is some suggestion that the absorption of calcium in combination with other cations may be essential for the synthesis of organic acids whereas traditionally it had been considered that the formation of calcium salts of these acids prevented their accumulation in toxic quantities within the cell.

III) The Effects of Physiological Age and Translocation on Calcium Levels in Higher Plants

Calcium is relatively immobile in plant tissues and will not move readily when it becomes deficient in the nutrient solution and, in contrast to phosphorus and potassium more calcium is present in the older than in the younger leaves.

However H. Saitoh (62) reports that in calcium deficiency situations in tomato plants this ion is transported from the lower, older leaves, to the newly formed ones and the lower the calcium status is in the plant the greater the transport rate. If calcium status is high the opposite flow might occur. Basically, similar conditions have been reported on peanut plants by Burkhart and Collins (15) where crystals of calcium oxalate in old leaves disappear at times of severe stress and are reformed in very young leaves indicating that some degree of redistribution takes place.

The question still remains whether this redistribution of calcium is sufficiently rapid or complete to meet the metabolic requirements of the younger tissues.

Calcium appears to have more importance during the early stages of plant growth when there are very high meristematic activities. V. Hernando and associates (30) have reported that calcium levels in tomato sap decreased constantly during the plants development and that this decrease was particularly evident during the first month after their germination.

These authors also found that the lower the calcium level the more readily N was absorbed and that the dry matter content was higher when adequate N and moderate amounts of calcium were provided.

IV) The Relationship Between Calcium and Earliness

Although no report linking calcium levels to early maturity was found its influence on growth and ion absorption may have a marked effect on this phenomena.

If we accept Sommer's hypothesis regarding the influence of phosphorus in enhancing early maturity (66) similar effects could be due to calcium, since its action in promoting or inhibiting the uptake of other ions would be due not only to the increase in growth it may cause but also due to its effects on the availability of the other ions in the soil solution. This factor however is much more complex for calcium than for phosphorus.

Recent experiments by D.A. Hegwood (29) on the effects of soil calcium levels on mineral concentrations in lima bean seedlings have shown that increases in calcium levels also increase the amounts of barium, copper and the Ca:Mg and the Ca:Sr ratios in above ground tissues while decreasing the levels of P, K, Mg, Zn, Mo, Mn, Fe and Al. In root tissues, only the calcium levels and the Ca:Mg ratio were increased while the P, Ba, Zn, B, Mo and Mn levels decreased. These effects, although beneficial in detoxifying some ions that otherwise would be in toxic amounts might, through the reduction of phosphorus, delay maturity.

Furthermore high calcium levels appear to inhibit rather than promote growth (7, 46, 49) by precipitating phosphorus as calcium phosphates, thus making it unavailable. Calcium also, by hardening the root tips, can inhibit root hair growth. These effects could be factors in delaying maturity.

Calcium has also been found in experiments done in cotton plant cells by Rehfeld and Jensen (57) to reduce the movement of all types of products

such as photosynthetic products, amino acids and organic acids. This in turn might reduce the metabolic activity of the plant and thus retard maturation.

It would appear that if any relationship exists between earliness and calcium levels in the nutrient solution or calcium levels in the plant it would be very dependent on the amounts of calcium applied and of the balance of other ions. While small amounts of calcium that might be required to detoxify other ions and to form the middle lamella could enhance growth and thus have a positive indirect effect on maturity, larger amounts, when these functions have already been fulfilled could have the opposite result.

Finally recent experiments in corn and rumex plants by Poovaiah and Leopold (56) have shown that added calcium delays leaf senescence due to the fact that senescence is probably a consequence of the deterioration of membrane compartments in the leaf cells.

By retarding senescence, calcium applications could also influence maturity. Especially in leafy crops maturity could be considered to be retarded by this effect since they are harvested at a senescent stage. However senescent leaves have very low metabolic activities and extremely low or negative net assimilation rates. By keeping them active for a longer period of time an actual enhancement of maturity might be achieved due to the faster growth induced.

C. Factor's Affecting Shoot:Root Ratio and Its Possible Relationship To Early Maturity

The shoot-root ratio is influenced by reciprocal correlative influences between the roots and the aerial parts of the plant (44, 24). Environmental conditions are responsible to a large extent for the kind and magnitude of these correlative influences. The nutritional factors, nitrates in particular, seem to be one of the most important variables determining these relationships.

High nitrate availability in the nutrient media has been shown by Turner (76) to increase the shoot:root ratio. This is mainly due to the influence nitrates have on the internal food relations of plants.

At low nitrate concentrations most nitrates absorbed are utilized in the synthesis of amino acids in the roots and the carbohydrates necessary for this process are translocated down from the leaves; these amino acids in turn, are used in protein synthesis during root growth. The tops, to which a very small proportion of the nitrates is available, are therefore somewhat deficient in proteins.

When more nitrates are present in the nutrient solution a larger proportion of them is available to the shoots. The shoots may thus synthesize more protoplasmic proteins which in turn may enhance vegetative growth.

Another important factor that influences the shoot:root ratio is the supply of carbohydrates within the plant (44). A decrease in photosynthetic rates or any other factor decreasing the amount of carbohydrates will in general increase the shoot:root ratio while its increase will, in contrast decrease this index.

Plants grown in the shade for example have higher shoot:root ratios

than the ones grown under adequate light intensities.

Conflicting reports are given for the effect of removing flowers and developing fruits. Meyer and Anderson (44) indicate that removal of foliage decreases the shoot:root ratios mainly by inducing an increase in root growth. Van der Post and Van der Meys (79) in experiments conducted on tomatoes, cucumbers and capsicum peppers reported that the removal of flowers and fruits in these crops kept the shoot:root ratio constant.

The relationship of photoperiodism to shoot:root ratio has been studied by Roberts and Struckmeyer (61) and reported on by Meyer and Anderson in their Plant Physiology textbook. These authors found that long day plants have higher shoot:root ratios under long photoperiod conditions. Short day plants have higher shoot:root ratios under short photoperiod conditions.

Available moisture has also been proven, as early as 1914, to influence this ratio in experiments conducted by F.S. Harris (28).

It is evident that shoot:root ratios are influenced by many factors and may influence earliness in several different ways depending on the particular conditions of the plant and of the environment under study.

High shoot:root ratios appear to be directly correlated to an increase in growth. This would probably enhance maturity according to A.L. Sommers hypothesis (66) referred to in the phosphorus review. On the other hand low carbohydrate availability in the plant can produce very high shoot:root ratios whereas high carbohydrate levels are associated with low shoot:root ratios. Since carbohydrate concentrations increase with maturity, shoot:root ratios could be expected to decrease with

increased maturity.

The idea that a more efficient or proportionally larger root system could have a positive effect on maturity, although perhaps oversimplified, appears to be reasonable. A plant that has a proportionally larger or more efficient root system may be able to provide better for the moisture and nutrient requirements of its aerial part. This would be a definite advantage for a faster uptake of the elements required for the plant nutrition. These elements can eventually become limiting factors and thus enhance maturity. The purpose of this section of our study has been to investigate this possibility.

D. Factors Affecting Net Assimilation and Its Possible Relationship To Early Maturity

I) Net Assimilation In Relation To Earliness

The net assimilation of carbon dioxide by the plant can be defined as the difference between the amount of carbon dioxide taken up by photosynthesis and the amount released by respiration per unit time.

The changes that occur hour by hour and day by day in this net assimilation process are largely responsible for the productivity of vegetation, either wild or cultivated (41) since this is the main process that plants have to increase in dry weight and thus produce healthy growth.

Therefore it is very probable that net assimilation rates have a basic influence on the early maturity of specific cultivars of crops.

The fact that species from areas where the growing season is short appear to have a relatively high photosynthetic capability, compensating in part for their shorter growth period (44) seems to corroborate this fact. This capability seems to be related mainly to their capacity to take better advantage of several factors such as longer daylight hours. They appear to lack the photosynthetic efficiency which some tropical plants such as sugarcane possess.

Several factors or combinations of factors can affect net assimilation rates due to their effect either on photosynthesis, dark respiration, photorespiration, or on all three.

II) Factors Affecting Net Assimilation

Before going into the different factors affecting net assimilation it is necessary to realize that even if for simplicity purposes we normally

talk of "maximum", "optimum" and "minimum" values for each of them, really these values do not exist as such. In net assimilation, as in most other metabolic processes, we are not looking at individual, totally isolated factors but rather at a number of them interacting with one another and the rate of the process is limited by the rate of the "slowest" one. This principle was enunciated by Blackman (9) in his "Principle of Limiting Factors". With this in mind let us proceed to briefly review some of these factors.

Carbon dioxide concentration in the atmosphere plays a major role in photosynthesis and thus in net assimilation. In general terms, an increase in the concentration of carbon dioxide in the surrounding atmosphere increases the photosynthetic rate, until some other factor, as light, becomes limiting. The injection of carbon dioxide in the greenhouse atmosphere is a well known practice used particularly by flower growers to improve growth.

Light is another of the main factors influencing net assimilation since the energy stored by green plants during photosynthesis can be supplied only by light. In general terms an increase in light intensity produces an increase in the photosynthetic rate until some other factor, usually carbon dioxide, becomes limiting. The "saturation point", that is the point at which no more increases in the photosynthesis rate can be achieved by increasing the light intensity, even in the absence of any limiting factors, changes from species to species and from cultivar to cultivar and even within the same plant depending on the phenological stage at which it is measured. This was demonstrated by T.F. Talling (70) in experiments on photosynthesis under natural conditions.

The lower limit at which plants can start to photosynthesize, even

if the other factors are kept at a, so-called "optimum", also varies depending on the species, cultivar and origin.

The time during which the plant is exposed to light can also have a bearing on net assimilation rates. Although generally the longer the exposure the larger the total amount of carbon dioxide fixed, the rates can decrease after a relatively long period of light exposure.

Experiments conducted by Upmeyer and Koller (78) on soya bean leaves in net photosynthetic rates diurnal trends have shown that after 10 hrs of light exposure, the rate of photosynthesis starts to decline to as little as 15% of the initial rate by the time the plants have reached a 16 hr photoperiod. A high starch level, impairing further synthesis of starch and leading to an increase in soluble carbohydrate level was advanced as a possible explanation of this decline. Neales and Incoll in a review of this hypothesis (48) present extensive evidence that seems to corroborate it. They recognize however, that there is not yet any definite proof that net assimilation rates and leaf carbohydrate content are causally associated.

Temperature is another factor closely related to net assimilation. Photosynthesis can occur over a wide range of temperatures. Freeland (25) has reported that positive net assimilation can occur in some species of conifers in temperatures as low as -6 C. Mayo et. al. (42) in "in situ" measurements of carbon dioxide assimilation by *Dryas integrifolia* in the Northwest Territories demonstrated that positive net assimilation occurred in this species at leaf temperatures as low as 1 C and in the laboratory at -4.5 C (personal communication).

The other extreme is represented by *Tidestronia oblongifolia*. Bjorkman and Pearry (8) on field studies conducted in Death Valley, California found that the "optimum" temperature for photosynthesis in this plant was 47 C leaf temperature and positive net assimilation values could be observed at temperatures over 50 C. Higher temperatures also increase the respiration rates and thus could have a negative effect on net assimilation since respiration increases exponentially.

The relationship between temperature and light has been studied by several authors (13, 31, 72).

Taylor and Rowley (72) have demonstrated that chilling temperatures combined with high light intensities cause a progressive reduction in the photosynthetic capacity of several tropical and subtropical species.

Brooking and Taylor (13) have advanced the hypothesis that this is due to some time and temperature dependent blockages that develop in the interconversion of C_4 pathway intermediates and possibly in the flow, to and from the sites of C_4 photosynthesis, of other intermediates.

Nutrient availability also has a marked effect on net assimilation.

The influence of phosphorus, a nutrient related to earliness as previously reviewed has been studied by Terry and Ulrich (73). In experiments with sugar beet (*Beta vulgaris* L. var. F5855441) cultivated hydroponically under standardized environmental conditions, phosphorus was removed from the nutrient solution 28 days after germination. Leaves grown with adequate phosphorus supply showed rates of CO_2 fixation three times as high as those of plants where the phosphorus supply had been discontinued. This decrease in rates was associated with increased mesophyll resistance during the first 15 days and with increased leaf

(mainly stomatal) diffusion resistance in the next 15 days. Phosphorus deficiency has also been associated with increases in chlorophyll content in leaf tissues (55).

Most other nutrients such as N, Mg, K, etc. also have a larger or lesser effect on net assimilation since any deficiencies can alter the metabolic balance of the plant.

Water stress and osmotic potentials (i.e. salinity) are other well known environmental factors that influence net assimilation.

Finally some internal factors such as chlorophyll content, hydration of the protoplasm, accumulation of end products of photosynthesis and leaf anatomy have been advanced as being partially responsible for the changes that can occur in net assimilation rates.

Although chlorophyll is the main pigment involved in photosynthesis its total content does not seem to be proportionally correlated to net assimilation rates.

Experiments by Willstatter and Stall (83) demonstrated, as early as 1918, that there is no proportional relationship between chlorophyll content and photosynthesis rates in the leaves of vascular plants.

It is important to point out however, coming once again to the main line of interest, that in experiments conducted in this University by M. Pandita (52) a direct negative correlation was found between a + b chlorophyll content in leaf tissues and days to maturity of different cultivars in three vegetable crops. The shorter the growing period of the cultivar, the lower the a + b chlorophyll content in leaf tissues. This in turn could be related to the phosphorus supply effects we have previously mentioned showing once more the complexity of the factors that regulate net assimilation, growth and earliness in green plants.

PART ONE

THE RELATIONSHIP BETWEEN PHOSPHORUS CONTENT OF LEAF TISSUES AND DAYS TO MATURITY OF THREE VEGETABLE CROPS

A. Materials and Methods (Common to Part One and Two).

One fruiting vegetable crop, Tomato *(Lycopersicon esculentum* L.) and two leafy vegetable crops, Cabbage *(Brassica oleracea* var. *capitata* L.) and Lettuce (*Lactuca sativa* var. *capitata* L.) were selected for these experiments. A fourth vegetable crop, Cauliflower (*Brassica oleracea* var. *botrytis* L.) was eliminated from the investigations because of the difficulty in maintaining the plants under growing conditions available.

Cultivars varying in their maturity periods from very early to very late and with at least 10 days difference in maturity among them, were selected.

Whenever possible preference was given to cultivars already well known and performance tested in western Canada.

The days to maturity considered for the different cultivars refers to the commercial and not to the physiological maturity. In the case of tomatoes it refers to the time elapsed between germination and the date the first 6 fruits were harvested, using, as the criteria for harvesting the stage at which the fruits started to show a pink coloration at their distal ends. For cabbage and lettuce the dates at which 60% of the heads were marketable was used as the maturity index. Marketable heads were considered to be those which had reached a peak in size and firmness.

Although these criteria are, by necessity, quite arbitrary, they are the ones commonly used in the vegetable industry and to provide a certain degree of standardization the average days to maturity of these cultivars during the years they had been tested at the University of Alberta, were used.

This was a minimum of 2 years of tests for Burpees Big Boy tomato cultivar and, in the maximum case, 9 years for the Early Fireball tomato cultivar. The average number of years tested for all cultivars in the 3 species used was 4 years.

The cultivars tested in these particular experiments were grown to maturity under field conditions in the summer of 1972 and again in the summer of 1973, and in the greenhouse of the Plant Science department in the winter 1972-73 and the summer of 1973.

Although some variation between these results and the averages were found it did not exceed $\pm$ 4 days in any case except for the greenhouse winter experiment where a general delay of about 10 days in maturity was experienced in all species. However, the differences between cultivars in maturity periods remained practically constant with only a difference of $\pm$ 2 days in the worst situation (winter greenhouse experiments for cabbage) so that their relative maturity in respect to each other was not affected.

The greenhouse experiments for all species were conducted at the Plant Science greenhouses, the field experiments were conducted at the Parkland Farm of the University of Alberta.

Simple correlation coefficients were calculated to determine whether there was a relationship between earliness and the factors studied during these investigations.

I) *Lycopersicon esculentum* L.

Three experiments were conducted with this crop. Two greenhouse experiments, one in the fall of 1972 and one in the summer of 1973, and one field experiment also in the summer of 1973. Four tomato cultivars were selected as follows:

Cultivar	Days to Maturity*	Source of Seed
Rocket	101	Stokes Seed Co., St. Catharines, Ont.
Early Fireball	117	Stokes Seed Co., St. Catharines, Ont.
Manitoba	124	Stokes Seed Co., St. Catharines, Ont.
Burpees Big Boy	134	Robertson Seed Co., Edmonton, Alta.

* Average days from germination to 6 ripe fruit in Edmonton area.

1. Greenhouse experiments.

The seeds were sown in small flats using 50-50 UC mixture (Apdx I) as the seedling media.

Row spacing was 6 cm and the greenhouse day/light temperatures were 24C/21C.

Two weeks after germination the plants were pricked out and transplanted into 15 cm plastic pots containing 50-50 UC mixture.

Thirty-six plants per cultivar were transplanted, two plants per pot.

The 18 pots per cultivar were divided in three replicates of 6 pots and the cultivars were located at random within each replication. The purpose of this procedure was to provide for the possible environmental variations in the greenhouse compartment.

Each pot was watered with 50 ml of a starter solution consisting of 7g/l of 10-52-17.

A second application of 10-52-17 at the same concentration per litre was given two weeks later.

2. Field experiment.

The plants were started in the same way as for the greenhouse experiments.

Two weeks after germination they were pricked out and transplanted into wooden flats 30 x 45 x 7.5 cm, with 12 plants per flat. The same starter solution as in the greenhouse experiment was applied.

Two weeks after pricking out the flats were taken to the University's Parkland Farm where for a week they were kept in open frames for hardening and were then transplanted into the field at a distance of 75 cm between plants and 150 cm between rows. Single plots consisted of 8 plants of a single cultivar. There were four cultivars, for a total of 32 plants in each replication and two replications were used for these experiments.

The cultivars were randomized within each replication and two guard rows of 'Rocket' were used at the ends of each replication.

Five hundred millilitres of starter solution consisting of 7g/l of 20-20-20 soluble fertilizer was applied just after transplanting and this application was repeated two weeks later.

The official classification of the soil at Parkland farm is Malmo Silt Loam (11) which is an eluviated black soil developed on lacustrine material.

The available nutrients in soil samples taken from the area in which the plants were grown was 62-67 kg/ha of available nitrogen, 56-62 kg/ha of available phosphorus and 336 kg/ha of available potassium. The soil contained a medium amount of organic matter and had a pH of approximately 5.7.

Collection of Samples

In both the greenhouse and field experiments the first tissue samples were collected three weeks after germination.

Dut to the small size of the seedlings at this stage all of the top growth from the point of development of the lowest leaf upwards was collected from one of the two plants in each pot. The remainder of the plant was up-rooted and discarded leaving only one plant per pot. In the case of the field experiment samples were taken from one full flat.

Five weeks after germination a second sample was taken following the Ward method (81). The fifth leaf from the growing tip was taken. Both the blade and the petiole were included. This was done for all plants in all replications and the samples of the same cultivars of all replications were then pooled. Additonal samples using the same procedure were taken 7 and 9 weeks after germination.

These pooled samples of each cultivar were dried at 60 $\pm$ 2C in a forced draft oven for 72 hours, ground to a fine powder with the aid of a grinding machine and then kept in hermetically sealed containers to avoid moisture inbibition prior to analysis.

Analysis

The fine powdered samples were analyzed on a "Technicon" Auto-analyzer (59) at the Soil and Feed Testing Laboratory of the Alberta Department of Agriculture.

The first step in the analysis was to weigh the samples to a tenth of a milligram approximation.

Samples were then wet ashed by the nitric-perchloric acid digestion

procedure. A 2:1 V/V nitric-perchloric acid mixture was prepared. Twelve ml of this mixture was added per each gram of sample. Samples and digestion mixture were placed in a Micro-Kjeldahl flask and a few glass beads added. The flasks were placed on a hot plate at about 250-300C until the digestion was completed as indicated by the clear color of the sample. Upon clearing, the sample was left to cool for 5 minutes.

After cooling, 100 ml of bidistilled water was added to each sample and mixed. Aliquots of 1.8 ml of these diluted samples were then placed in small vials. The vials were placed on a perforated disc alternated with vials containing only bidistilled water to avoid any "memory" effects.

The disc rotated at one minute intervals exposing subsequent vials to a sampling device that took an aliquot of the sample and, through a T connection, divided the aliquot into two portions, one for the phosphorus analysis and the other for the calcium analysis.

These portions continued to progress through two different capillary tubes toward a proportioning pump where each was mixed with the required amounts of the appropriate analytical reagents. The reagents also came through capillary tubes.

The phosphorus sample was mixed with a composite solution consisting of 1 g of ammonium metavanadate dissolved in 300 ml of distilled water, brought to the boil and mixed with 20 g of ammonium molybdate dissolved in 400 ml of water. The solutions were then mixed with 140 ml of nitric acid and diluted to 1 litre.

The calcium sample was mixed first with cresolphthalein complexone plus hydroxy quinoline and then with a base solution of 0.5 grams of KCN dissolved in 500 ml of distilled water plus 150 ml of diethylamine, then diluted to 1 litre.

The purpose of the hydroxy quinoline was to avoid magnesium interference.

Air was also added to both samples and each was mixed with its own reagents in a double mixing coil.

The calcium sample was immersed in a water bath at 39C since the reaction to follow is very sensitive to temperature and appears to progress better at this temperature.

Finally the phosphorus sample was subjected to a colorimeter determination with settings of 420 mμ and 15 mm flow cell. The settings for the calcium determination were 580 mμ and 8 mm flow cell.

The results of these two determinations were recorded simultaneously on a chart with a different colored line for each determination.

A set of standard solutions for both phosphorus and calcium were run through the autoanalyzer and the resulting graphs were used to plot the results obtained from the experimental samples. The results were expressed in parts per million on the ion in question. Parts per million data was converted to percentages of phosphorus and percentages of calcium in relation to total sample dry weight.

A detailed flow diagram of the technicon autoanalyzer is shown in Figure 1.

II) *Brassica oleracea* var. *capitata* L.

Four experiments were conducted with this crop: three greenhouse experiments, in the fall of 1972, the winter 1972-73 and the summer of 1973, and one field experiment in the summer of 1973. Four cabbage

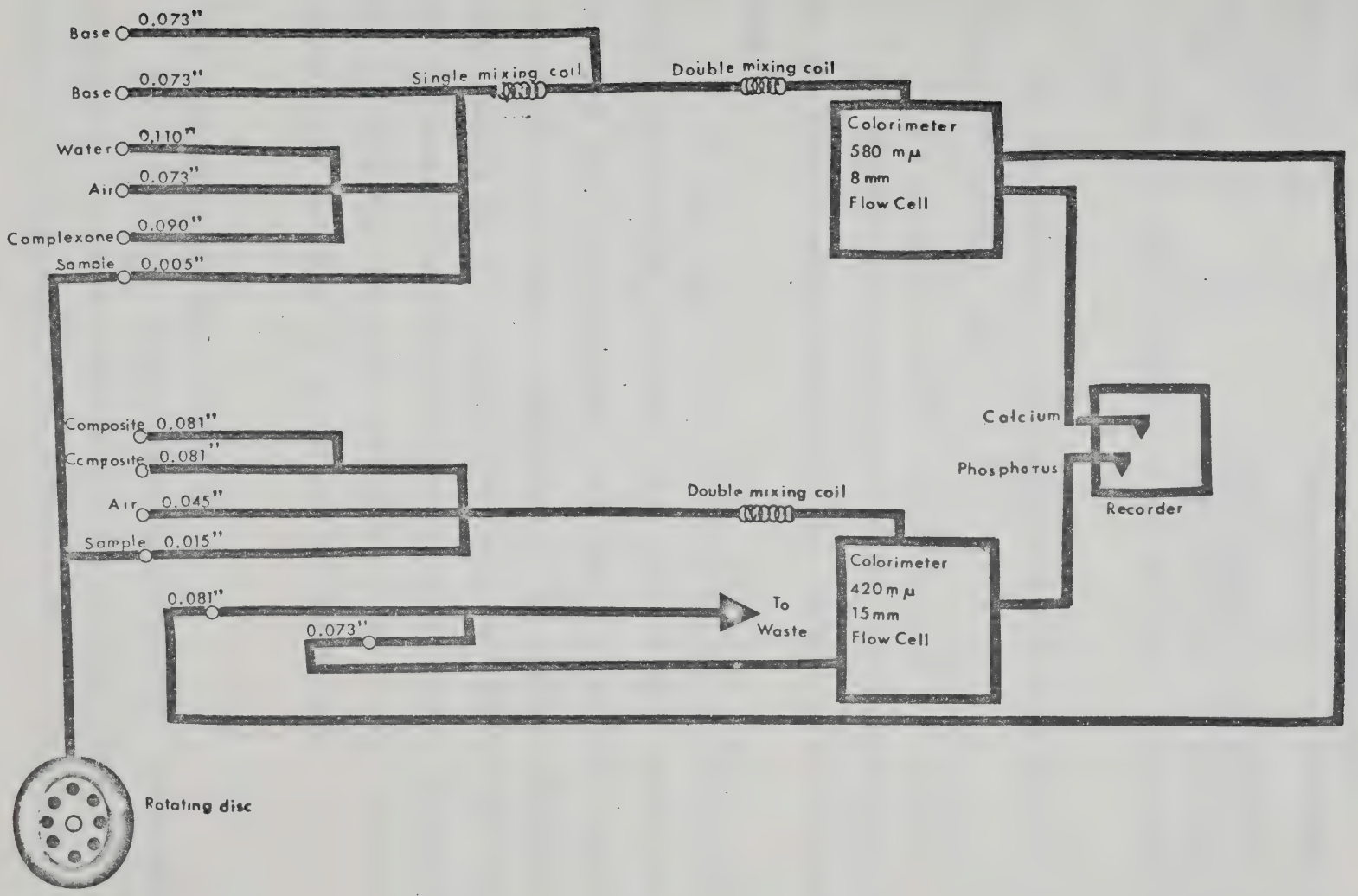

Fig. 1. "Technicon" autoanalyzer flow diagram.

cultivars were selected as follows:

Cultivar	Days to Maturity*	Source of Seed
Emerald Acre	80	Stokes Seed Co., St. Catharines, Ont.
Copenhagen Early Market	95	Stokes Seed Co., St. Catharines, Ont.
Sanibel	113	Stokes Seed Co., St. Catharines, Ont.
Triple Green	146	Stokes Seed Co., St. Catharines, Ont.

* Average days from germination to 60% marketable heads in the Edmonton area.

The same procedures as for tomatoes were followed for this species. The only differences being:

a) The greenhouse day/night temperatures were of 18C/15C.

b) The distance between plants in the field experiment was 45 cm and the distance between rows was 75 cm. Sanibel was used for guard rows.

c) The leaf samples for this crop were taken according to the Ulrich and Smith (65, 77) method. The youngest fully matured leaf, including leaf blade and petiole, was taken. In the first sample due to the very early stage of development of the seedlings no mature leaves were found so the full tops from the oldest leaf upwards were taken. For this reason plants were transplanted at the rate of two per plastic pot and after the sample was taken from one in each pot the rest of that seedling was discarded, as in the case of the tomatoes.

III) *Lactuca sativa* var. *capitata* L.

Three experiments were conducted with this crop: Two greenhouse experiments, one in the winter of 1972-73 and one in the summer of 1973 and one field experiment in the summer of 1973. Three cultivars were

selected as follows:

Cultivar	Days to Maturity*	Source of Seed
New York 515	103	A.E. McKenzie Seed Co., Edmonton, Alta.
Premier Great Lakes	118	Stokes Seed Co., St. Catharines, Ont.
Ithaca	128	Stokes Seed Co., St. Catharines, Ont.

* Average days from germination to 60% marketable heads in Edmonton area.

The same procedures as for tomatoes, with the same modifications stipulated for the cabbage experiments, were applied for this crop.

New York 515 was used for guard rows in the field experiment.

B. Results

I) Tomato

1. Greenhouse Experiments.

No significant correlations between % phosphorus and days to maturity of the cultivars studied were obtained for either the fall or winter experiments at any of the four harvest dates. Cultivars did differ in % phosphorus present in leaf tissues.

These results are presented in Tables 1 and 2.

2. Field Experiment.

No significant correlation between % phosphorus and maturity were obtained on any of the four harvest dates.

The total amount of phosphorus present in the plants was slightly higher than for the greenhouse grown plants.

These results are presented in Table 3.

In both the greenhouse and field experiments the highest total phosphorus in leaf tissues was found 5 weeks after germination.

II) Cabbage

1. Greenhouse Experiments.

a) Fall 1972 experiment

A correlation coefficient of -0.97, significant at the 5% level was obtained on the samples taken 9 weeks after germination.

No significant correlations were obtained at any other stage in this crop.

The results are presented in Table 4.

Table 1. The relationship between days to maturity and % Phosphorus content of leaf tissue in four cultivars of *Lycopersicon esculentum* L., three to nine weeks after germination (Greenhouse, Fall 1972).

Cultivars	% Phosphorus			
	Weeks After Germination			
	3	5	7	9
Rocket	.54	.74	.56	.62
Early Fireball	.64	.74	.60	.57
Manitoba	.73	.73	.63	.64
Burpees Big Boy	.57	.71	.55	.53
Correlation between % phosphorus in leaf tissue and days to maturity	0.34	-0.85	0.08	-0.56

Table 2. The relationship between days to maturity and % Phosphorus content of leaf tissue in four cultivars of *Lycopersicon esculentum* L., three to nine weeks after germination (Greenhouse, Summer 1973).

Cultivars	% Phosphorus			
	Weeks After Germination			
	3	5	7	9
Rocket	.55	.76	.59	.60
Early Fireball	.52	.79	.62	.57
Manitoba	.60	.78	.64	.66
Burpees Big Boy	.62	.72	.57	.52
Correlation between % phosphorus in leaf tissue and days to maturity	0.71	-0.43	0.08	-0.34

Table 3. The relationship between days to maturity and % Phosphorus content of leaf tissue in four cultivars of *Lycopersicon esculentum* L., three to nine weeks after germination (Field, Summer 1973).

Cultivars	% Phosphorus			
	Weeks After Germination			
	3	5	7	9
Rocket	.58	.79	.62	.68
Early Fireball	.51	.85	.64	.64
Manitoba	.63	.82	.70	.71
Burpees Big Boy	.68	.76	.62	.59
Correlation between % phosphorus in leaf tissue and days to maturity	0.63	-0.26	0.23	-0.52

Table 4. The relationship between days to maturity and % Phosphorus content of leaf tissue in four cultivars of *Brassica oleraceae* var. *capitata* L., three to nine weeks after germination (Greenhouse, Fall 1972).

Cultivars	% Phosphorus			
	Weeks After Germination			
	3	5	7	9
Emerald Acre	.42	.70	.72	.70
Copenhagen Market Early	.44	.59	.65	.68
Sanibel	.50	.61	.63	.65
Triple Green	.44	.67	.69	.63
Correlation between % phosphorus in leaf tissue and days to maturity	0.28	-0.01	-0.17	-0.97*

* Significant at 5% level.

b) Winter 1972-73 and summer 1973 experiments

No significant correlations were obtained at any stage in these two crops as presented in Tables 5 and 6 respectively.

In the winter experiment no samples were taken 9 weeks after germination as had been done with the other crops.

2. Field Experiment.

On the crop grown at Parkland Farm in the summer of 1973 no significant correlations were obtained on any of the 4 samples taken as can be seen in the results presented in Table 7.

III) Lettuce

1. Greenhouse Experiments.

a) Winter 1972-73 experiment

A correlation coefficient of +0.99 significant at the 5% level was obtained 3 weeks after germination. At 5 and 7 weeks after germination, negative, correlation coefficients of -0.53 and -0.83 respectively were obtained. They were not significant.

These results are presented in Table 8.

b) Summer 1972 experiment

Negative correlation coefficients of -0.61, -0.60 and -1.00 were obtained at 3, 5 and 7 weeks after germination. The latter was significant at the 1% level.

These results are presented in Table 9.

2. Field Experiment.

A correlation coefficient of -0.99, significant at the 5% level was obtained with the samples taken 5 weeks after germination and with the

Table 5. The relationship between days to maturity and % Phosphorus content of leaf tissue in four cultivars of *Brassica oleraceae* var. *capitata* L., three to seven weeks after germination (Greenhouse, Winter 1972-73).

Cultivars	% Phosphorus		
	Weeks After Germination		
	3	5	7
Emerald Acre	.45	.74	.74
Copenhagen Market Early	.44	.64	.65
Sanibel	.52	.75	.63
Triple Green	.44	.71	.64
Correlation between % phosphorus in leaf tissue and days to maturity	0.02	0.06	-0.70

Table 6. The relationship between days to maturity and % Phosphorus content of leaf tissue in four cultivars of *Brassica oleraceae* var. *capitata* L., three to nine weeks after germination (Greenhouse, Summer 1973).

Cultivars	% Phorphorus			
	Weeks After Germination			
	3	5	7	9
Emerald Acre	.39	.71	.70	.68
Copenhagen Market Early	.41	.64	.68	.65
Sanibel	.52	.71	.66	.60
Triple Green	.39	.69	.69	.66
Correlation between % phosphorus in leaf tissue and days to maturity	0.06	0.07	-0.20	-0.24

Table 7. The relationship between days to maturity and % Phosphorus content of leaf tissue in four cultivars of *Brassica oleraceae* var. *capitata* L., three to nine weeks after germination (Field, Summer 1973).

Cultivars	% Phosphorus			
	Weeks After Germination			
	3	5	7	9
Emerald Acre	.31	.67	.76	.71
Copenhagen Market Early	.40	.62	.68	.69
Sanibel	.55	.75	.65	.52
Triple Green	.50	.70	.65	.66
Correlation between % phosphorus in leaf tissue and days to maturity	0.73	0.47	0.60	0.34

Table 8. The relationship between days to maturity and % Phosphorus content of leaf tissue in three cultivars of *Lactuca sativa* var. *capitata* L., three to seven weeks after germination (Greenhouse, Winter 1972-73).

Cultivars	% Phosphorus		
	Weeks After Germination		
	3	5	7
New Yorker	.35	.64	.53
Premier Gt. Lakes	.42	.57	.48
Ithaca	.48	.61	.49
Correlation between % phosphorus in leaf tissue and days to maturity	0.99*	-0.53	-0.83

* Significant at 5% level.

Table 9. The relationship between days to maturity and % Phosphorus content of leaf tissue in three cultivars of *Lactuca sativa* var. *capitata* L., three to seven weeks after germination (Greenhouse, Summer 1973).

Cultivars	% Phosphorus		
	Weeks After Germination		
	3	5	7
New Yorker	.33	.66	.52
Premier Gt. Lakes	.35	.56	.50
Ithaca	.28	.61	.49
Correlation between % phosphorus in leaf tissue and days to maturity	-0.61	-0.60	-1.00**

** Significant at 1% level.

samples taken 7 weeks after germination. No significant correlations were obtained at either 3 or at 9 weeks after germination.

These results are presented in Table 10.

In both the greenhouse and field experiments the highest total phosphorus in leaf tissues was found 5 weeks after germination.

Table 10. The relationship between days to maturity and % Phosphorus content of leaf tissue in three cultivars of *Lactuca sativa* var. *capitata* L., three to nine weeks after germination (Field, Summer 1973).

Cultivars	% Phosphorus			
	Weeks After Germination			
	3	5	7	9
New Yorker	.29	.74	.64	.51
Premier Gt. Lakes	.28	.69	.59	.44
Ithaca	.38	.67	.53	.46
Correlation between % phosphorus in leaf tissue and days to maturity	0.75	-0.99*	-0.99*	0.77

* Signficant at 5% level.

C. Discussion and Conclusions

Of the three vegetable species assessed during these experiments the most consistently significant correlations were obtained with lettuce.

No significant correlation coefficients were obtained at any point during the tomato experiments.

It is interesting to note that, using other cultivars, Pandita and Andrew found highly significant negative correlations between % phosphorus and days to maturity in tomatoes (53).

There were marked changes on total % phosphorus present in leaf tissues within cultivars, from season to season. Since all factors except light intensity and photoperiod were kept constant throughout the year in the greenhouse experiment, it appears that photoperiodism and light intensity may be responsible for these variations. Future experiments could be conducted in growth chambers where the light factors could be controlled. Unfortunately these facilities were not available during these investigations.

Phosphorus content in tomatoes increased from the 3rd week to the 5th week of plant development and decreased from the 5th to the 7th week remaining relatively constant from the 7th to the 9th week.

The increased supply of phosphorus, due to fertilization, could be responsible for the increase observed 5 weeks after germination. A slight depletion of this supply, combined with some translocation effects, could be responsible for the decrease observed from the 5th to the 7th week after germination.

The stabilization of the phosphorus levels in leaf tissues 9 weeks after germination was particularly surprising since the two earlier

cultivars and Rocket in particular had already started flowering and a sharp decrease, due to the translocation effects was expected at this stage.

However, when, after the experiments, the plants were grown to maturity no defficiency symptoms were observed in the foliage and the fruiting and yields were normal apparently indicating that enough phosphorus reserves were still available in the growing media. This availability could have reduced or nullified to a certain extent, the translocation effects that could have been expected in a phosphorus deficient condition.

Similar results were observed in the cabbage experiments. Only in one situation, 9 weeks after germination in the 2 greenhouse experiments, conducted in the fall of 1972 was a significant negative correlation between % phosphorus in leaf tissues and days to maturity observed. All the other samples taken during these investigations were not statistically significant.

It is interesting to note that M.L. Pandita using other cultivars found a significant positive correlation between % phosphorus and days to maturity in this species (52).

The same variations within cultivars from season to season that were observed in tomatoes were repeated in this species. Photoperiodism and light intensity are probably the factors responsible for this phenomenon as has been suggested for tomatoes.

The change in phosphorus levels in leaf tissues with plant development are not as marked as the ones observed for tomatoes. Phosphorus appears to increase from the 3rd to the 7th week after germination whereas from the 7th to the 9th week the levels remain stable, decrease or

increase depending on the cultivar and the time of year at which the experiment was conducted although the general tendency seems to be a slight decrease due probably to translocation of phosphorus from the older to the younger leaves.

Lettuce, was the species with the most consistently significant correlation was obtained.

Although in the winter 1972 greenhouse experiment a positive significant correlation coefficient was obtained 3 weeks after germination, this was the only case in which a positive correlation was obtained.

Data from the summer, greenhouse and field experiments indicate negative correlations between total phosphorus levels in leaf tissues and days to maturity 7 weeks after germination in the field experiment.

In seven of the ten samplings of this species, the correlation coefficients obtained, even when not statistically significant, were negative suggesting that in general the earlier cultivars had higher phosphorus levels.

The initial increase from the 3rd to the 5th week after germination in the % phosphorus present in leaf tissues of this species could be explained by an increase in phosphorus supply in the nutrient solution. The second application of 10-52-17 at 7g/l of fertilizer solution was made 4 weeks after germination. This hypothesis is consistent with previous findings that phosphorus content of plant tissue is directly proportional to its supply in the nutrient solution (17, 27, 23) and is also consistent with the results obtained in the tomato crop.

After this peak was attained 5 weeks after germination the decreases to lower levels at 7 weeks and in the summer crop at 9 weeks could be explained by a depletion of the phosphorus supply in the growing media and

also by the fact that the accummulation of carbohydrates as the plant gets older tends to dilute the phosphorus concentration (16).

The negative correlation coefficients between days to maturity and phosphorus levels for this species are in agreement with previous reports (52).

The effect of phosphorus in enhancing most metabolic activities might explain these results either directly or, as Sommers suggested (66) indirectly. The enhancement of these metabolic activities will have an effect on growth and through it on the uptake of other nutrients. When uptake cannot keep pace with growth this can contribute to earlier maturity.

No explanation can be given with the data available for the positive correlation between phosphorus levels in leaf tissues and days to maturity that was obtained in the 1973 winter experiment.

This correlation is not only opposite to the other correlations found for this species but also to the general trend of the whole series of lettuce experiments.

PART TWO

THE RELATIONSHIP BETWEEN CALCIUM CONTENT IN LEAF TISSUES AND DAYS TO MATURITY OF THREE VEGETABLE CROPS

A. Materials and Methods (Common to Part One and Two).

See Part One, page 27

B. Results

I) Tomato

1. Greenhouse Experiments

In the fall 1972 experiment no significant correlation was obtained at any of the four dates for which the crop was tested, however the correlation coefficients were negative in all stages of development studied.

In the summer 1973 experiment a correlation coefficient of -0.96, significant at the 5% level was obtained on the sample taken 7 weeks after germination.

The correlation coefficients obtained at the other 3 dates at which the crop was tested were not statistically significant and with the exception of the sample taken 5 weeks after germination all were negative.

The results for the fall 1972 experiment are presented in Table 11.

The results for the summer 1973 greenhouse experiment are presented in Table 12.

2. Field Experiments

The correlation coefficients obtained during this experiment were not significant at any of the four dates on which samples were taken.

The trend to negative correlations for this species was also manifested in this experiment at all four dates on which tests were made.

The results of the experiment are presented in Table 13.

In both the greenhouse and field experiments the highest total calcium in leaf tissues was found 5 weeks after germination.

Burpees Big Boy in all the calcium experiments with tomato plants, was consistently out of line with the other three cultivars trend to show a higher calcium % in leaf tissues with a shorter growing period. Significant correlation coefficients between % calcium and days to maturity could have been obtained at most samplings if only the other three cultivars had been considered.

II) Cabbage

1. Greenhouse Experiments

a) Fall 1972 experiment

A correlation coefficient of +0.98, significant at the 5% level was obtained on the sample taken 3 weeks after germination. No significant correlations were obtained at later dates.

The results of this experiment are presented in Table 14.

b) Winter 1972-73 experiment

No significant correlation coefficients were obtained either 3 or 5 weeks after germination. A correlation coefficient of +0.97 at the 5% level was obtained with the samples taken 7 weeks after germination.

The results of this experiment are presented in Table 15.

Table 11. The relationship between days to maturity and % Calcium content of leaf tissue in four cultivars of *Lycopersicon esculentum* L., three to nine weeks after germination (Greenhouse, Fall 1973).

Cultivars	% Calcium			
	Weeks After Germination			
	3	5	7	9
Rocket	1.96	2.52	2.36	2.34
Early Fireball	1.79	2.38	2.21	1.81
Manitoba	1.52	2.30	2.00	1.74
Burpees Big Boy	1.77	2.37	2.18	1.81
Correlation between % calcium in leaf tissue and days to maturity	-0.62	-0.80	-0.68	-0.85

Table 12. The relationship between days to maturity and % Calcium content of leaf tissue in four cultivars of *Lycopersicon esculentum* L., three to nine weeks after germination (Greenhouse, Summer 1973).

Cultivars	% Calcium			
	Weeks After Germination			
	3	5	7	9
Rocket	1.88	2.04	2.23	2.62
Early Fireball	1.81	1.95	1.86	2.81
Manitoba	1.63	1.87	1.83	2.51
Burpees Big Boy	1.77	2.04	1.73	2.38
Correlation between % calcium in leaf tissue and days to maturity	-0.63	0.20	-0.96*	-0.60

* Significant at 5% level.

Table 13. The relationship between days to maturity and % Calcium content of leaf tissue in four cultivars of *Lycopersicon esculentum* L., three to nine weeks after germination (Field, Summer 1973).

Cultivars	% Calcium			
	Weeks After Germination			
	3	5	7	9
Rocket	1.93	3.65	2.05	2.66
Early Fireball	1.77	3.62	1.58	2.31
Manitoba	1.35	3.16	1.87	2.01
Burpees Big Boy	1.79	3.29	1.60	2.06
Correlation between % calcium in leaf tissue and days to maturity	-0.45	-0.77	-0.71	-0.93

Table 14. The relationship between days to maturity and % Calcium content of leaf tissue in four cultivars of *Brassica oleracea* var. *capitata* L., three to nine weeks after germination (Greenhouse, Fall 1972).

Cultivars	% Calcium			
	Weeks After Germination			
	3	5	7	9
Emerald Acre	1.61	3.51	3.25	2.47
Copenhagen Early Market	1.93	3.74	3.57	2.77
Sanibel	2.53	3.72	3.35	2.72
Triple Green	2.98	3.78	3.87	3.19
Correlation between % calcium in leaf tissue and days to maturity	0.98*	-0.73	0.83	0.83

* Significant at 5% level.

Table 15. The relationship between days to maturity and % Calcium content of leaf tissue in four cultivars of *Brassica oleracea* var. *capitata* L., three to seven weeks after germination (Greenhouse, Winter 1972-73).

Cultivars	% Calcium		
	Weeks After Germination		
	3	5	7
Emerald Acre	2.80	3.59	3.27
Copenhagen Early Market	2.65	3.74	3.35
Sanibel	2.84	3.78	3.40
Triple Green	3.01	3.79	3.77
Correlation between % calcium in leaf tissue and days to maturity	0.80	0.80	0.97*

* Significant at 5% level.

c) Summer 1973 experiment

A correlation coefficient of +0.96 significant at the 5% level was obtained on the sample taken 3 weeks after germination. Although the correlation coefficients obtained in later dates were relatively high they didn't attain statistically significant levels.

The results of this experiment are presented in Table 16.

2. Field Experiment

Positive correlation coefficients, significant at the 5% level were obtained on the samples taken 3, 7 and 9 weeks after germination. No significant correlation was obtained for the sample taken five weeks after germination.

The results of this experiment are presented in Table 17.

III. Lettuce

1. Greenhouse Experiments

a) Winter 1972-73 experiment

Although the correlation coefficients were relatively high no statistically significant levels were attained at any point during this experiment.

The results of this experiment are presented in Table 18.

b) Summer 1972 Experiment

A correlation coefficient of +1.00, significant at the 1% level was obtained 5 weeks after germination. A correlation coefficient of +0.99, significant at the 5% level was obtained 7 weeks after germination. No significant correlation was obtained on the earlier sample taken 3 weeks after germination.

The results of this experiment are presented in Table 19.

Table 16. The relationship between days to maturity and % Calcium content of leaf tissue in four cultivars of *Brassica oleracea* var. *capitata* L., three to nine weeks after germination (Greenhouse, Summer 1973).

Cultivars	% Calcium			
	Weeks After Germination			
	3	5	7	9
Emerald Acre	1.73	3.48	3.37	2.88
Copenhagen Early Market	2.19	3.88	3.69	2.79
Sanibel	2.49	3.67	3.65	2.96
Triple Green	2.79	3.95	3.89	3.39
Correlation between % calcium in leaf tissue and days to maturity	0.96*	0.72	0.90	0.91

* Significant at 5% level.

Table 17. The relationship between days to maturity and % Calcium content of leaf tissue in four cultivars of *Brassica oleracea* var. *capitata* L., three to nine weeks after germination (Field, Summer 1973).

Cultivars	% Calcium			
	Weeks After Germination			
	3	5	7	9
Emerald Acre	1.59	3.49	2.90	2.30
Copenhagen Early Market	2.00	4.30	3.14	2.52
Sanibel	2.51	3.76	3.12	2.59
Triple Green	2.89	3.96	3.42	2.61
Correlation between % calcium in leaf tissue and days to maturity	0.97*	0.27	0.95*	0.95*

* Significant at 5% level.

Table 18. The relationship between days to maturity and % calcium content of leaf tissue in three cultivars of *Lactuca sativa* var. *capitata* L., three to seven weeks after germination (Greenhouse, Winter 1972-73).

Cultivars	% Calcium		
	Weeks After Germination		
	3	5	7
New Yorker	1.05	1.05	1.41
Premier Gt. Lakes	1.38	1.15	1.43
Ithaca	1.38	1.48	1.54
Correlation between % calcium in leaf tissue and days to maturity	0.92	0.92	0.88

Table 19. The relationship between days to maturity and % Calcium content of leaf tissue in three cultivars of *Lactuca sativa* var. *capitata* L., three to seven weeks after germination (Greenhouse, Summer 1973).

Cultivars	% Calcium		
	Weeks After Germination		
	3	5	7
New Yorker	1.10	1.18	1.40
Premier Gt. Lakes	1.14	1.37	1.48
Ithaca	1.12	1.52	1.69
Correlation between % calcium in leaf tissue and days to maturity	0.60	1.00**	0.99*

* Significant at 5% level.

** Significant at 1% level.

2. Field Experiments

No significant correlations were obtained during this experiment although the correlation coefficient of +0.95 obtained 5 weeks after germination was quite near the significant level of +0.99 for the degrees of freedom of our sample.

The results of this experiment are presented in Table 20.

Table 20. The relationship between days to maturity and % Calcium content of leaf tissue in three cultivars of *Lactuca sativa* var. *capitata* L., three to nine weeks after germination (Field, Summer 1973).

Cultivars	% Calcium			
	Weeks After Germination			
	3	5	7	9
New Yorker	0.77	1.23	0.87	0.76
Premier Gt. Lakes	0.78	1.65	0.86	0.66
Ithaca	0.94	1.69	1.03	0.78
Correlation between % calcium in leaf tissue and days to maturity	0.77	0.95	0.75	0.04

C. Discussion and Conclusions

Significant correlation coefficients between calcium content of leaf tissues and earliness were found for all crops at some stage during these investigations.

Tomatoes showed a negative correlation coefficient, significant at the 5% level only once during these experiments. The significant correlation was found 7 weeks after germination in our 1973 summer greenhouse experiment. Eleven of the twelve samples analyzed had, even if not significant, negative correlation coefficients. This appears to indicate that, in this species, lower calcium levels in leaf tissues are associated with later cultivars. This is particularly true for Rocket, Early Fireball and Manitoba that showed this trend consistently through all the calcium experiments. Burpees Big Boy showed slightly higher % calcium than would have been expected if it had followed the same trend as the other three cultivars.

Genetical differences between Burpees Big Boy, an eastern cultivar, and the other three cultivars used in these experiments that are extensively used in the prairie region might be responsible for the differences among them in their relationship to earliness.

The highest calcium levels in tomato leaf tissues were found 5 weeks after germination with decreasing amounts at 7 weeks and at 9 weeks after germination.

The most consistent correlations were obtained by the cabbage experiments particularly, during the field trial where positive significant correlations between days to maturity and calcium content of the leaf tissues were obtained 3, 7 and 9 weeks after germination.

Similar significant correlations were obtained 3 weeks after germination during the fall and summer greenhouse experiments while in the winter experiment this correlation was found only 7 weeks after germination.

These results suggest that, for cabbage, a negative correlation between earliness and calcium content in leaf tissues, that is a positive correlation between days to maturity and calcium levels, exists.

The earlier cultivars therefore apparently tend to have less calcium in tissue samples than the later ones.

The inhibiting action that calcium exercises on the uptake of other nutrients (29), particularly phosphorus whose relation to earliness we have already mentioned and studied, and the effect of calcium in inhibiting the movement of all kinds of products from the cells (57) might explain these findings.

These two inhibiting effects of high levels of calcium in plant tissues may slow down several physiological activities which in turn could retard plant growth and thus delay maturity in similar ways to those that phosphorus enhances it. Previous reports on the effects of high levels of calcium in plants on shoot and root growth, yields, membrane permeability and movement of products from the cell seem to be in agreement with this hypothesis (7, 46, 57, 69). These results, and hypothesis, would seem to be contradictory to our findings for tomato where the earlier cultivars are the ones that appear to be associated with higher calcium levels in leaf tissues.

A possible explanation could be that in the particular case of tomatoes the calcium amounts present in leaf tissues were not high enough to cause the inhibiting of growth while rather detoxifying other nutrients

that would otherwise be in toxic amounts something that in itself will be beneficial on growth and indirectly on maturity.

Evidence that calcium can enhance rather than inhibit plant growth under these conditions has also been reported by several authors (14, 67). In cabbage, the calcium correlation with earliness appears to be higher at the earlier stages of plant development, where, at the third week after germination, three of the four crops showed significant correlations.

Photoperiodism and calcium supply in the growing media might modify this situation. Photoperiodism could be responsible for the delay in the winter crop to show a significant correlation coefficient until the 7th week after germination. Even with the same cultivar there was very much variation in % calcium present at different seasons. Temperature, soil, water supply, fertilization and all other factors, except photoperiodism and light intensity were kept constant in the greenhouse cabbage experiments so it would be logical to assume that photoperiodism and light intensity are responsible for these changes within cultivars.

Calcium supply appears to have affected the field experiments where significant correlation coefficients again were apparent after transplant into the field that is on the 7th and 9th week after germination.

The variation in calcium content of leaf tissues during plant development seems to have followed a similar pattern to the one found for tomatoes where an initial increase in calcium content from the 3rd to the 5th week was followed by a decrease at the 7th and 9th week. This decrease was particularly sharp from the 7th to the 9th week while very slight from the 5th to the 7th week.

The dilution of calcium amounts present in leaf tissues by the

increase in carbohydrates in older plants might explain this phenomenon.

In the lettuce crops significant results were only found during our summer experiment. A highly significant positive correlation was observed between calcium level in leaf tissue and days to maturity 5 weeks after germination. A significant correlation at the 5% level was found 2 weeks later during this same experiment.

Although the correlation coefficients during our winter and our field experiments did not reach significant levels it is interesting to note that the correlation coefficients found were particularly high again at 5 weeks after germination approaching quite close if not actually reaching the 5% level of significance.

In all samples taken the correlation coefficients found were positive regardless of whether or not they were significant thus reinforcing the observation that a higher calcium content in leaf tissues was found in the later cultivars. The same hypothesis advanced for our cabbage results can apply here.

It could be concluded that apparently there is a correlation between % calcium in leaf tissues and earliness. This correlation is not the same for all species. On cabbage and lettuce it appears to be a negative correlation between % calcium and earliness while on tomatoes it appears to be a positive one, the earlier cultivars showing higher calcium levels in leaf tissues.

Factors such as genetic background, time of year, stage of development of the plant, calcium supply and relative levels achieved can have a bearing on this relationship.

Future experiments using a larger number of cultivars and/or growing chambers where total environmental control can be achieved would probably

provide further information on this complex relationship.

PART THREE

THE RELATIONSHIP BETWEEN SHOOT:ROOT RATIO AND DAYS TO MATURITY OF THREE VEGETABLE CROPS

A. Materials and Methods

The same three species choosen for the previous experiments tomato, cabbage and lettuce were used during these investigations.

I) *Lycopersicon esculentum* L.

Three experiments were conducted with this crop. One in the fall of 1972, one in the winter of 1972-73 and one in the spring of 1973.

The cultivars choosen for these investigations and the growing techniques were the same as the ones described for the previous tomato experiments. The only difference was that twenty-four instead of thirty-six plants were transplanted per cultivar, one plant per pot, and no replications were made.

Sampling

Three weeks after germination four plants were taken at random from each cultivar. The pots were removed and the soil carefully washed off the roots by a low pressure stream of water over a fine sieve.

Each plant was then cut at soil level and the roots, including the ones that had fallen on the seive, were collected separately from the aerial portion.

The four root samples of each cultivar were put in a Petry dish and dried for 48 hours in a draft oven at 60 $\pm$2 C. The same was done for the aerial portion.

Immediately after their removal from the oven the dried samples were weighed on a microbalance and the shoot:root ratio was calculated.

The same procedure was repeated two and four weeks later i.e. five and seven weeks subsequent to germination.

II) *Brassica oleracea* var. *capitata* L.

Three experiments were conducted with this crop. One in the fall of 1972, one in the winter of 1972-73 and one in the spring of 1973.

The cultivars choosen for these investigations and the growing techniques were the same as the ones described for the previous cabbage experiments. The differences were the same as the ones described in the shoot:root ratio tomato experiments.

III) *Lactuca sativa* var. *capitata* L.

Two experiments were conducted with this crop. One in the winter of 1972-73 and one in the spring of 1973.

The cultivars choosen for these investigations and the growing techniques were the same as the ones described for the previous lettuce experiments. The differences were the same as the ones described in the shoot:root ratio tomato experiments.

The analysis method was also the same as for the tomato shoot:root ratio experiments.

B. Results

I) Tomato

1. Fall 1972 Experiment

The correlation of shoot:root ratio with days to maturity was significant at the 5% level only at 5 weeks after germination when a positive correlation coefficient of 0.96 was found.

Earlier cultivars had a lower shoot:root ratio than later ones.

The correlation coefficient for the experiments as a whole, that is the shoot:root ratio correlation for the total of the three dates at which the plants were tested with the days to maturity of the specific cultivars was 0.89 and thus not significant mainly due to the low correlation coefficients obtained for the samples taken at 3 weeks and 7 weeks.

The results of this experiment are presented in Table 21.

2. Winter 1972-1973 Experiment

A highly significant correlation at the 1% level was obtained 3 weeks after germination where the correlation coefficient was +0.99. With the seven week sample a significant correlation at the 5% level was obtained. The correlation coefficient at this date was 0.98. With the samples taken 5 weeks after germination a correlation coefficient of +0.82 was obtained, but the coefficient was not statistically significant.

The correlation for the experiment as a whole was significant at the 5% level showing a correlation coefficient of +0.97.

The results of this experiment are presented in Table 22.

3. Summer 1973 Experiment

This experiment showed a significant positive correlation at the 5%

Table 21. The relationship between days to maturity and Shoot:Root ratio of four cultivars of *Lycopersicon esculentum* L. three to seven weeks after germination (Fall 1972).

Cultivars	Shoot:Root Ratio			
	Weeks After Germination			
	3	5	7	Total
Rocket	1.48	2.98	2.95	7.41
Early Fireball	4.35	4.05	3.42	11.82
Manitoba	2.38	5.89	7.03	15.3
Burpees Big Boy	3.01	6.33	4.56	13.9
Correlation between shoot:root ratio and days to maturity	0.43	0.96*	0.57	0.89

* Significant at 5% level.

Table 22. The relationship between days to maturity and Shoot:Root ratio of four cultivars of *Lycopersicon esculentum* L. three to seven weeks after germination (Winter 1972-73).

Cultivars	Shoot:Root Ratio			
	Weeks After Germination			
	3	5	7	Total
Rocket	1.15	3.48	2.53	7.16
Early Fireball	1.89	3.31	3.14	8.34
Manitoba	2.13	4.05	3.90	10.08
Burpees Big Boy	2.80	4.65	4.35	11.80
Correlation between shoot:root ratio and days to maturity	0.99**	0.82	0.98*	0.97*

* Significant at 5% level.

** Significant at 1% level.

level on all the three dates that samples were taken.

The correlation coefficients at 3, 5 and 7 weeks after germination were +0.96; +0.95; +0.98 respectively while the correlation coefficient for the whole experiment was +0.96.

The correlation for the whole experiment was also significant at the 5% level.

The results of this experiment are presented in Table 23.

II) Cabbage

1. Fall 1972 Experiment

A significant correlation, at the 5% level was obtained 5 weeks after germination when the correlation coefficient was +0.99. With the 7 week samples a positive correlation coefficient of 1.00 was obtained. The correlation was significant at the 1% level.

The correlation coefficient of +0.86 for the whole experiment was not significant due mainly to the very low +0.22 correlation found on the sample taken 3 weeks after germination.

The results of this experiment are presented in Table 24.

2. Winter 1972-1973 Experiment

Although no significant correlations were found for any of the 3 dates at which samples were taken the experiment as a whole gave a correlation coefficient of +1.00, significant at the 1% level.

The results of this experiment are presented in Table 25.

3. Summer 1973 Experiment

A correlation coefficient of +0.99, significant at the 5% level was obtained on the sample taken 3 weeks after germination. No significant correlations were obtained at later dates and the

Table 23. The relationship between days to maturity and Shoot:Root ratio of four cultivars of *Lycopersicon esculentum* L. three to seven weeks after germination (Summer 1973).

Cultivars	Shoot:Root Ratio			
	Weeks After Germination			
	3	5	7	Total
Rocket	1.71	3.42	3.17	8.27
Early Fireball	2.05	4.20	3.70	9.95
Manitoba	2.61	6.04	4.13	12.78
Burpees Big Boy	3.24	7.09	4.88	15.21
Correlation between shoot:root ratio and days to maturity	0.96*	0.95*	0.98*	0.96*

* Significant at 1% level.

** Significant at 5% level.

Table 24. The relationship between days to maturity and Shoot:Root ratio of three cultivars of *Brassica oleracea* var. *capitata* L. three to seven weeks after germination (Fall 1972).

Cultivar	Shoot:Root Ratio			
	Weeks After Germination			
	3	5	7	Total
Emerald Acre	1.21	3.04	2.59	6.94
Copenhagen Early Market	2.56	3.60	2.92	9.08
Triple Green	1.89	4.25	3.86	10.00
Correlation between shoot:root ratio and days to maturity	0.22	0.99*	1.00**	0.8621

* Significant at 5% level.

** Significant at 1% level.

Table 25. The relationship between days to maturity and Shoot:Root ratio in three cultivars of *Brassica oleracea* var. *capitata* L. three to seven weeks after germination (Winter 1973-1973).

Cultivars	Shoot:Root Ratio			
	Weeks After Germination			
	3	5	7	Total
Emerald Acre	0.92	3.92	1.85	6.69
Copenhagen Early Market	1.45	3.53	2.36	7.34
Triple Green	1.89	4.62	2.93	2.93
Correlation between shoot:root ratio and days to maturity	0.94	0.48	0.96	1.00**

** Significant at 1% level.

correlation coefficient for the whole experiment, of +0.79 was not significant either.

The results of this experiment are presented in Table 26.

III) Lettuce

1. Winter 1972-73 Experiment

No significant correlations were found either for the sample taken at 3 weeks after germination or at the one taken 5 weeks after germination and neither was the correlation coefficient for the whole experiment of +0.74 statistically significant.

The results of this experiment are presented in Table 27.

2. Summer 1973 Experiment

A correlation coefficient of +1.00, significant at the 1% level was obtained for the sample taken 7 weeks after germination. The correlation coefficients of -0.34 three weeks after germination, of +0.21 five weeks after germination and the correlation coefficient of +0.87 obtained for the whole experiment were not statistically significant.

The results of this experiment are presented in Table 28.

Table 26. The relationship between days to maturity and Shoot:Root ratio in three cultivars of *Brassica oleracea* var. *capitata* L. three to seven weeks after germination (Summer 1973).

Cultivars	Shoot:Root Ratio			
	Weeks After Germination			
	3	5	7	Total
Emerald Acre	1.09	3.24	2.12	6.45
Copenhagen Early Market	1.29	4.49	2.79	8.57
Triple Green	1.66	4.19	3.17	9.02
Correlation between shoot:root ratio and days to maturity	0.99*	0.49	0.89	0.79

* Significant at 5% level.

Table 27. The relationship between days to maturity and Shoot:Root ratio in three cultivars of *Lactuca sativa* var. *capitata* L. three to five weeks after germination (Winter 1972-1973).

Cultivars	Shoot:Root Ratio		
	Weeks After Germination		
	3	5	Total
New Yorker	1.62	5.01	6.63
Premier Gt. Lakes	2.25	7.28	9.53
Ithaca	2.30	6.28	8.58
Correlation between shoot:root ratio and days to maturity	0.94	0.65	0.74

Table 28. The relationship between days to maturity and Shoot:Root ratio in three cultivars of *Lactuca sativa* var. *capitata* L. three to seven weeks after germination (Summer 1973).

Cultivars	Shoot:Root Ratio			
	Weeks After Germination			
	3	5	7	Total
New Yorker	1.49	6.28	5.00	12.77
Premier Gt. Lakes	3.31	8.33	8.62	20.26
Ithaca	2.52	6.50	10.41	19.43
Correlation between shoot:root ratio and days to maturity	-0.34	0.21	1.00**	0.87

** Significant at 1% level.

C. Discussion and Conclusions

Some positive, significant correlations between shoot:root ratio and days to maturity were obtained in all three species.

Tomatoes, particularly during the summer experiment showed the most consistent results. Significant, positive correlations, between shoot: root ratio and days to maturity were observed in six out of the nine dates at which samples of tomatoes were taken during these experiments. In all cases, including the ones that were not significant, positive correlations were obtained.

The correlation coefficients for the total data of two of the three experiments (Tables 22 and 23) was also significant at the 5% level.

These results suggest that a relationship exists between the shoot: root ratio of a cultivar and the time it takes to mature. The lower the shoot:root ratio, the earlier the cultivar can be expected to mature.

In the case of the tomato cultivars this relationship can be observed from the earliest stages of plant development (3, 5 and 7 weeks after germination) but this does not preclude its continuance at later dates not included in the scope of these experiments.

A possible explanation for these observations was referred to, in the literature review (p. 22).

A plant that has proportionally a larger root system to provide for the nutritional and moisture requirements of its aerial part would have a definite advantage for a faster uptake of elements that eventually can become limiting factors and thus enhance maturity.

This would be similar to Sommer's (66) explanation for the enhancing

effect that phosphorus seems to have on maturity although in this case the faster uptake is not through the indirect hastening of metabolic activities but rather to a proportionally larger absorption surface.

It would also agree with the observations reported by Meyer and Anderson (44) that an increase in carbohydrate content in the plant would decrease the shoot:root ratio since we know that carbohydrates increase with increased maturity and thus lower shoot:root ratios can be expected in earlier maturing cultivars.

In the cabbage experiments, positive significant results were observed both in the fall and in the summer experiments and while no individual, significant, correlation coefficients were obtained during the winter experiment, the correlation coefficient for the total data of that crop was significant at the 1% level.

In lettuce, where only two experiments were conducted, a positive, significant, correlation coefficient was found only during our summer experiment, seven weeks after germination.

The fact that no significant correlation coefficients were found, during our winter experiments for either cabbage or lettuce, may be partially due to the adverse light conditions prevailing during that season that were responsible for poor head formation or abnormal plant development on both crops.

Furthermore, for both crops and particularly for lettuce it was very difficult to save the whole root system due to the extreme brittleness and fine texture of the roots of these species. If we observe the results we can see that in most cases when no significant correlations were obtained this was due to one cultivar showing an abnormally high shoot: root ratio. Since particular care was taken to have uniform plants, at

least in reference to the aerial parts, these results could be explained by the loss of part of the root systems during the washing process.

The same hypothesis explaining the positive correlation between shoot:root ratios and days to maturity could be applied for these crops.

Further work is suggested to determine whether a particular kind of development of the root systems i.e. horizontal vs. vertical growth, is significantly different among cultivars and if it has a bearing on earliness. Previous investigations (54), although not directly orientated towards this objective, seem to indicate that this might be the case.

We believe that the strong possibility that days to maturity are positively correlated to shoot:root ratio of different cultivars within a species has been proven by these experiments.

PART FOUR

THE RELATIONSHIP BETWEEN NET ASSIMILATION AND DAYS TO MATURITY OF THREE VEGETABLE CROPS

Two vegetable species: tomato and cabbage were selected for this experiment.

The plants were grown in the Plant Science greenhouses of the University of Alberta.

A. Materials and Methods

I) *Lycopersicon esculentum* L.

Three tomato cultivars were selected as follows:

Cultivar	Days to Maturity*	Source of Seed
Rocket	101	Stokes Seed Co., St. Catharines, Ont.
Early Fireball	117	Stokes Seed Co., St. Catharines, Ont.
Burpees Big Boy	134	Robertsons Seed Co., Edmonton, Alta.

* Average days from germination to 6 ripe fruit in Edmonton area.

The seeds were sown in small flats using 50-50 UC mixture (Apdx I) as the seedling medium.

Row spacing was 6 cm and the day/night greenhouse temperature was 25C/20C. Two weeks after germination the plants were pricked out and transplanted into 15 cm plastic pots containing 50-50 UC mixture.

Twelve plants were transplanted for each cultivar taking special care to choose as uniform seedlings as possible.

Each plant was watered with 50 ml of a starter solution consisting of 7 g/l of 10-52-17.

A second, 50 ml application of 10-52-17, was given two weeks later.

Analysis

Five weeks after germination the plant closest to the median size for the cultivar was selected and taken, 2 hours in advance of the experiment to a growth chamber where an MSA Model 200 LIRA Infrared Gas Analyzer was installed.

The IRGA was warmed up for 30 minutes befor use to allow the cells to reach a controlled temperature of 65-75C. This temperature was well above that to be expected for the ambient air and would take care of any temperature fluctuations that may occur in the sample and reference gas streams. These fluctuations might otherwise cause changes in pressure and volume and thus affect the concentration readings. The analyzer was zeroed and spanned using standard gases as described by Mayo, et al. (42).

A flow rate of 4.7 l/minute was used for this experiment.

After all these initial operations were performed the 5th leaf from the top of the selected plant was set in an hermetically sealed curette.

The temperature of the growth chamber was set at 23 C.

Twenty minute readings at three different light intensities of 0.139, 0.193 and 0.289 cal. cm^{-2} $min.^{-1}$ respectively and one in darkness, were taken.

Ten minute intervals between readings were used to check the zero line and to allow the plant to adapt to the new environmental conditions. The same measurements were then taken at 11°C.

When all measurements had been taken the curette was removed and the leaf was dried for 48 hours in a draft oven at 60 $\pm$2 C. The same procedure was used for all cultivars.

The dried leaves were weighed in a microbalance and the results expressed as mg of CO_2 fixed per hour, per gram of dry weight. Two weeks

later, 7 weeks after germination, exactly the same procedure was repeated for the three cultivars.

II) *Brassica oleraceae* var. *capitata* L.

Three cabbage cultivars were selected as follows:

Cultivars	Days to Maturity*	Source of Seed
Emerald Acre	80	Stokes Seed Co., St. Catharines, Ont.
Sanibel	113	Stokes Seed Co., St. Catharines, Ont.
Triple Green	146	Stokes Seed Co., St. Catharines, Ont.

* Average days from germination to 60% harvestable heads in the Edmonton area.

The day/night greenhouse temperature was 18C/15C.

The youngest fully developed leaf was selected for the readings.

The CO_2 flow was 5.5 l/minute.

The rest of the growing and analysis procedures were the same as the ones described for tomatoes.

Due to lack of availability of the IRGA measurements were taken at one date only (6 weeks after germination).

B. Results

Due to the limited size of the sample no statistical analysis of the results was possible.

The net assimilation results were expressed as milligrams of CO_2 fixed per hour, per gram of dry weight of leaves.

The conversion formula was: mg CO_2 g^{-1} hr^{-1} = Δ CO_2 ppm x 1.96 mg CO_2/1000 l x flow in l CO_2/minute x 60 minutes/hr x 1/dryweight in grams.

Light intensity was expressed as Calories cm^{-2} $minute^{-1}$. This energy measure is considered to be a better expression of radiation intensities than the traditional foot candles.

One cal. cm^{-2} $minute^{-1}$ is considered to be equivalent to approximately 4.4×10^4 ft. cndls. for a light meter the peak efficiency of which is similar to the human eye.

The results are shown in a graphic form to facilitate the observation of the net assimilation trends and curves of the cultivars studied under the different environmental conditions used in these experiments.

The results of the different experiments are shown as follows:

I) Tomato

1) Five weeks after germination, 11 C ----- Figure 2

2) Five weeks after germination, 23 C ----- Figure 3

3) Seven weeks after germination, 11 C ----- Figure 4

4) Seven weeks after germination, 23 C ----- Figure 5

II) Cabbage

1) Six weeks after germination, 11 C ----- Figure 6

2) Six weeks after germination, 23 C ----- Figure 7

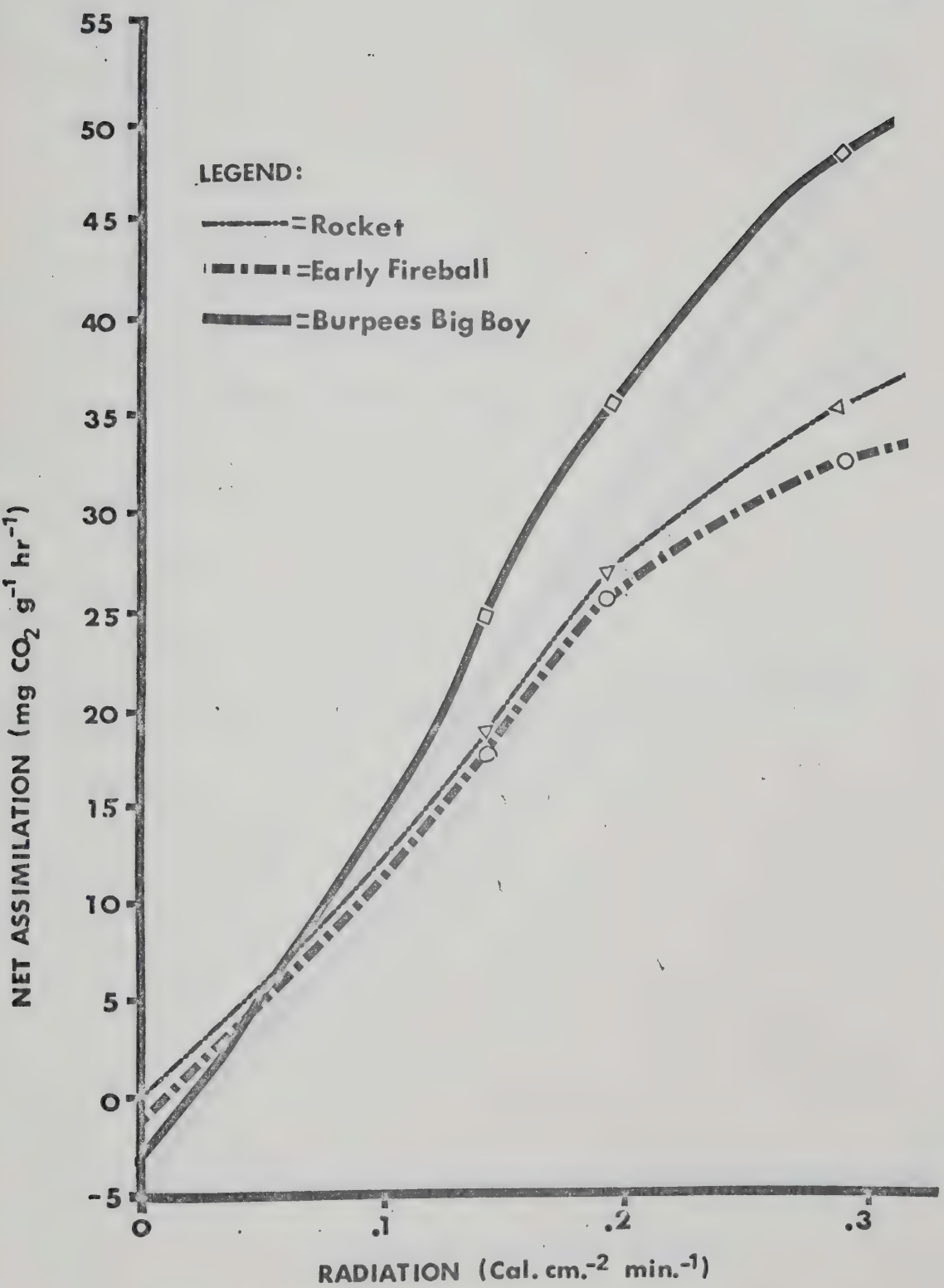

Fig. 2. Net assimilation of three tomato cultivars five weeks after germination at various light levels and at a constant temperature of 11 C.

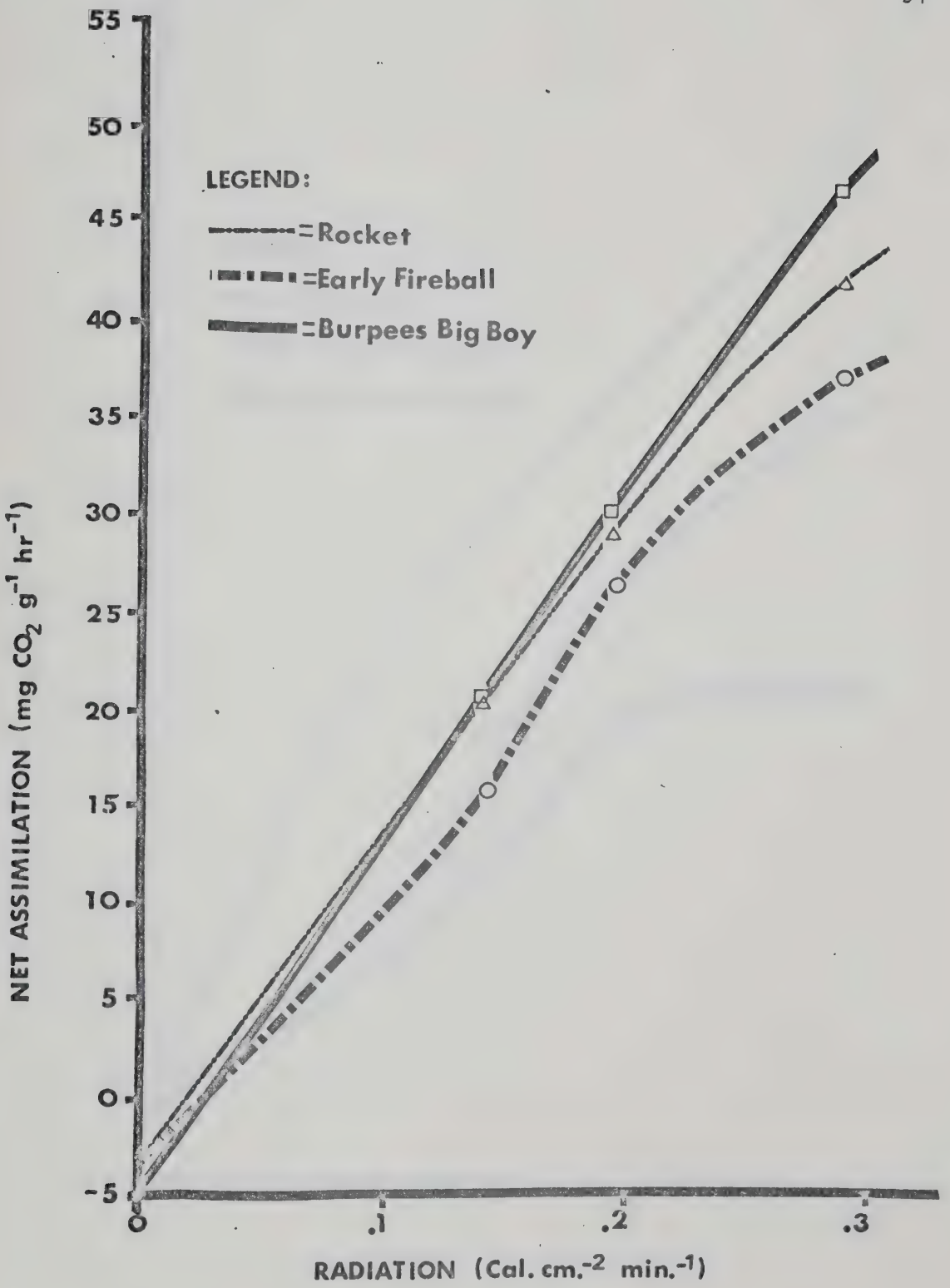

Fig. 3. Net assimilation of three tomato cultivars five weeks after germination at various light levels and at a constant temperature of 23 C.

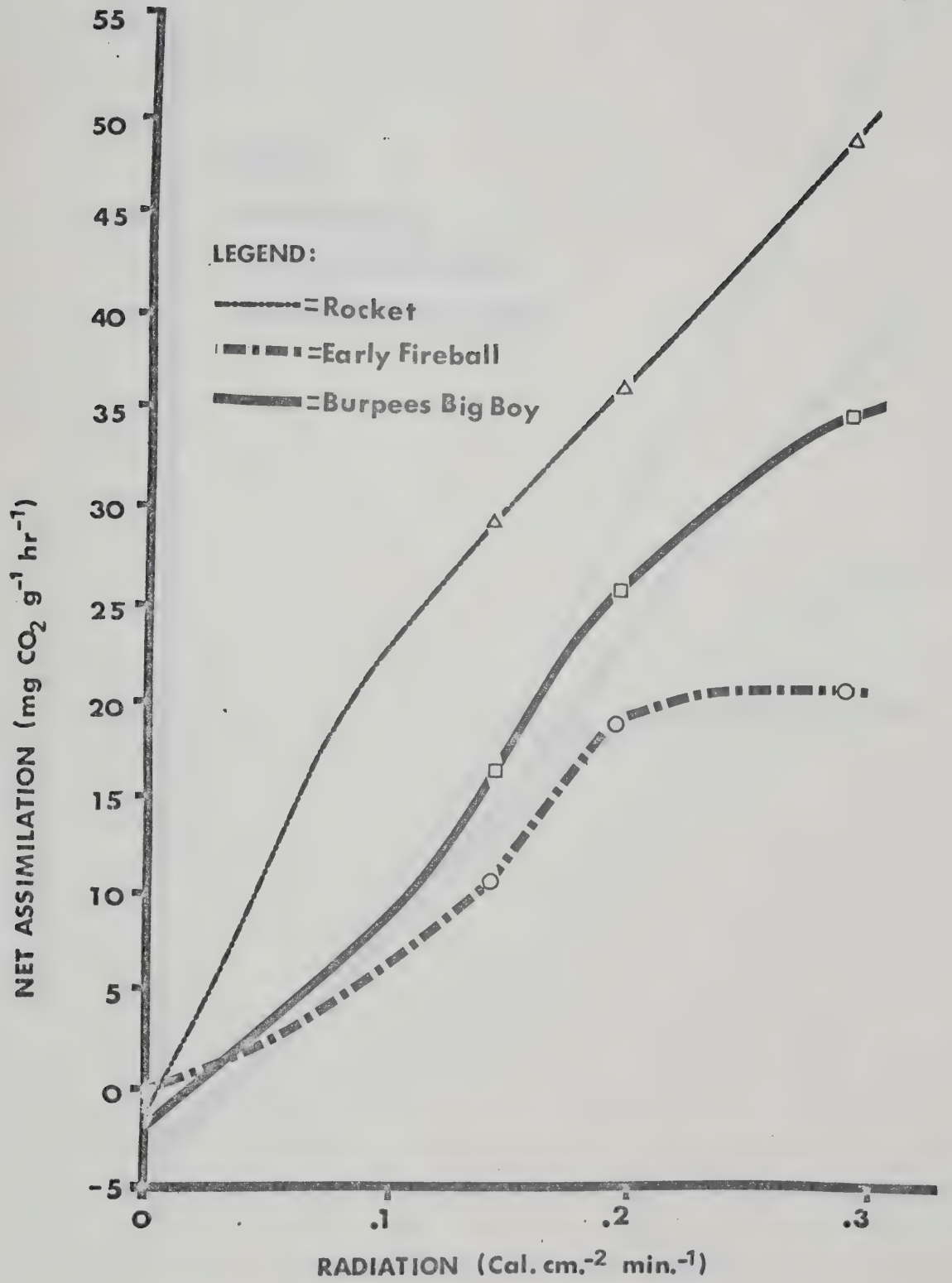

Fig. 4. Net assimilation of three tomato cultivars seven weeks after germination at various light levels and at a constant temperature of 11 C.

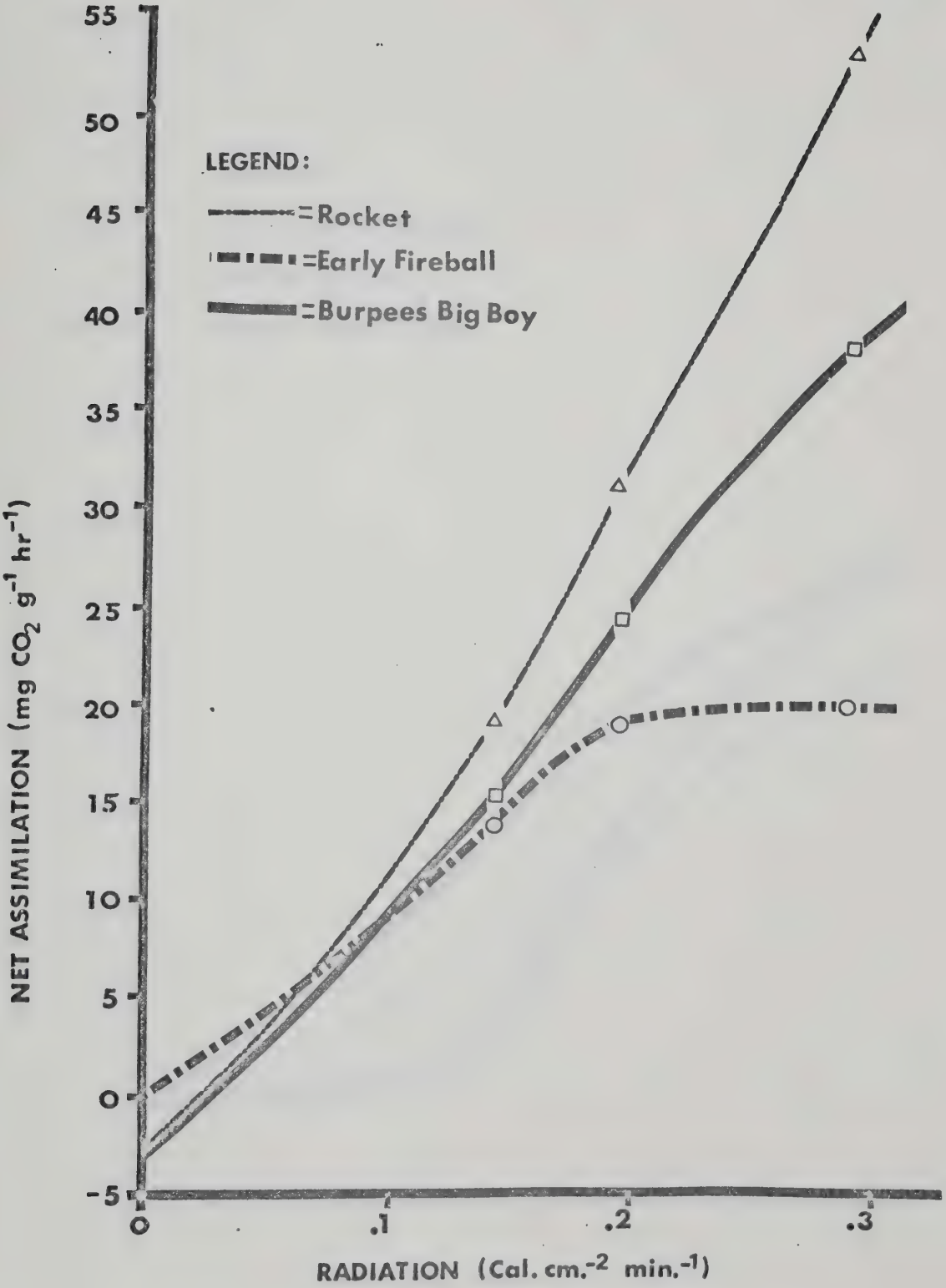

Fig. 5. Net assimilation of three tomato cultivars seven weeks after germination at various light levels and at a constant temperature of 23 C.

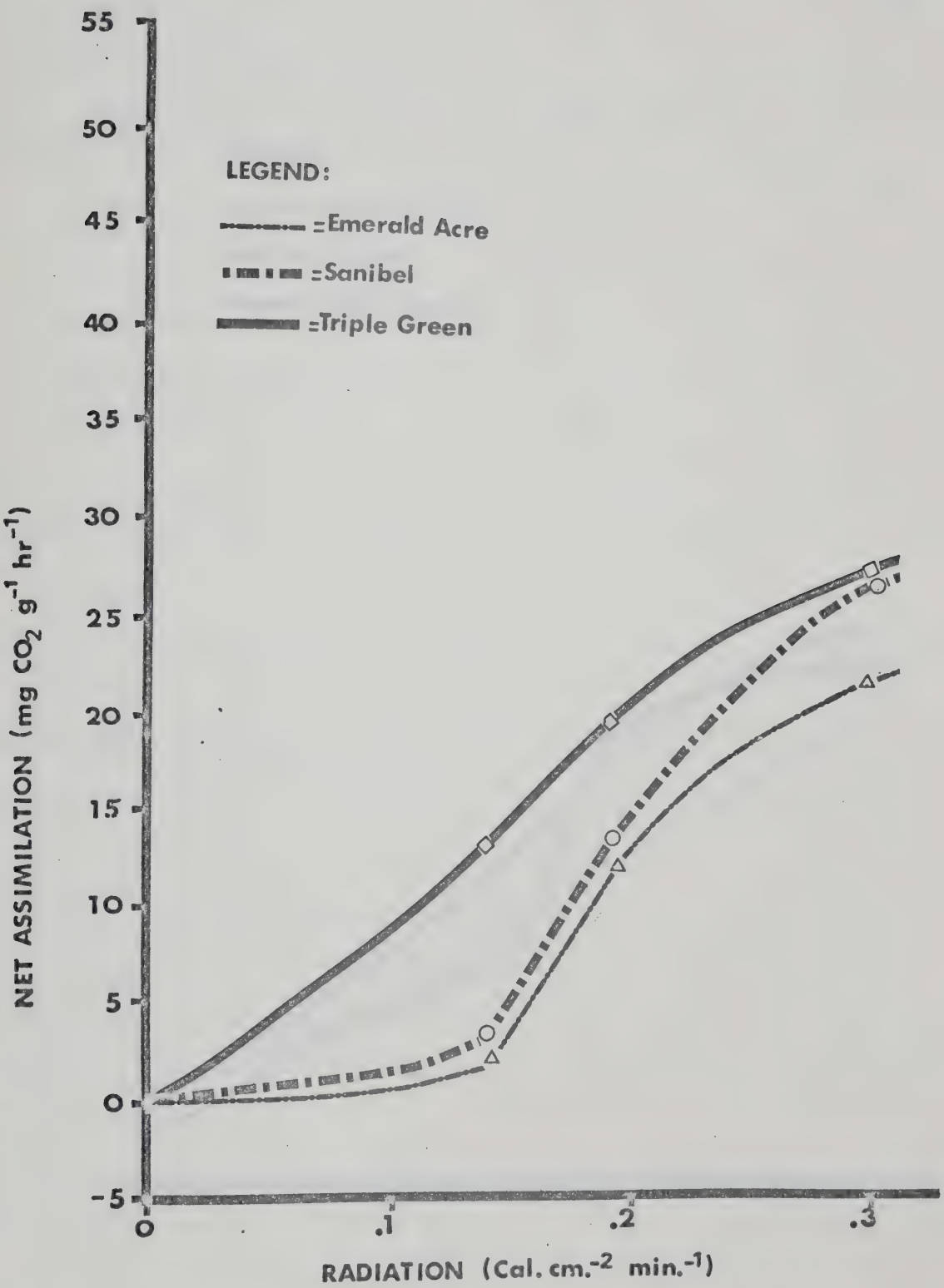

Fig. 6. Net assimilation of three cabbage cultivars six weeks after germination at various light levels and at a constant temperature of 11 C.

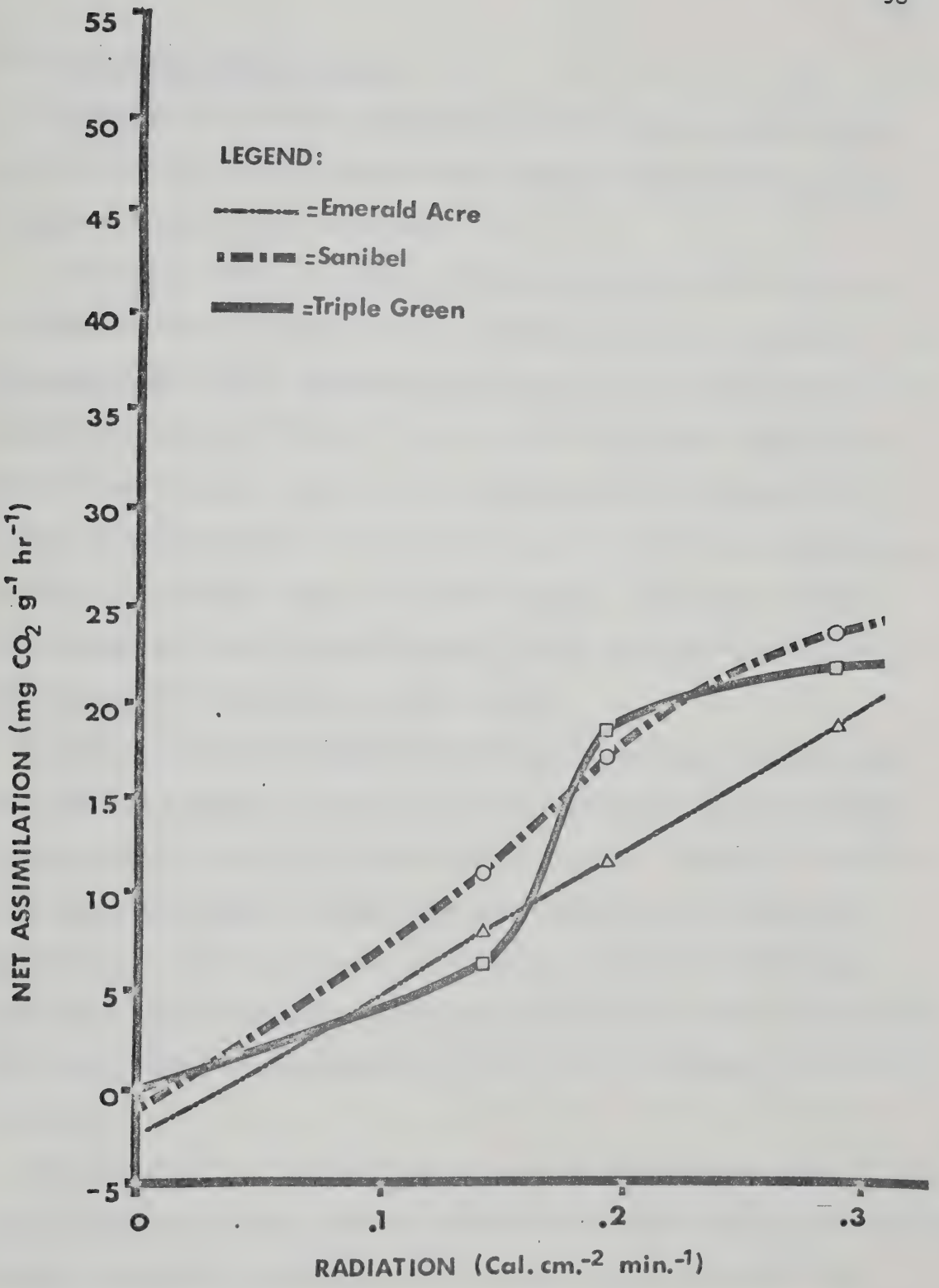

Fig. 7. Net assimilation of three cabbage cultivars six weeks after germination at various light levels and at a constant temperature of 23 C.

C. Discussion and Conclusions

Although due to the limited scope of this experiment we are not able to make any definite conclusions, certain interesting facts are suggested from the data available.

The age of the plant appears to affect the ability of the plants to photosynthesize. This effect is not the same for all cultivars. If we compare the results obtained for the tomato experiments 5 weeks after germination (Figures 2 and 3) with the ones obtained 7 weeks after germination (Figures 4 and 5) we can see that Burpees Big Boy, the latest maturing cultivar, seems to be a much more efficient photosynthesizer at the earlier stages of its development. A decrease of 29% in the average net assimilation rates at 11 C was observed from the 5th to the 7th week of this cultivar's development.

Rocket, our earliest maturing cultivar, showed on our experiments the opposite tendency. While Burpees Big Boy appears to perform better at the earlier stages of its development, Rocket's average net assimilation rates were higher 7 weeks after germination than 5 weeks after germination. At 11 C an increase of 23% was observed in the average net assimilation rates when we compare the values obtained at the 5 week and 7 week stages of development. At 23 C the increase was in the order of 12%.

Early Fireball, a cultivar the maturity of which lies between the other two cultivars mentioned, showed, as Burpees Big Boy, a very marked decrease in the average net assimilation rates values with an increase in age from 5 to 7 weeks after germination. This decrease both at 11 C and at 23 C was in the order of 33% of the average net assimilation values obtained 5 weeks after germination. In the case of Early Fireball

however this decrease was mainly due to a reduction of the light saturation point of the cultivar that at light intensities as low as 0.193 cal. cm^{-2} min^{-1} was already saturated not responding to any further light increase as we can see in Figures 4 and 5.

The effect of an increase in light intensities on the other two tomato cultivars (Rocket and Burpees Big Boy) was always an almost proportional increase in their average net assimilation rates at both stages of development studied for both 11 and 23 C measurements. Showing that neither of these two cultivars had, under the light intensities used, reached its light saturation point. Early Fireball as we have mentioned before showed this kind of response only during the measurements taken 5 weeks after germination. In the second set of measurements, taken 7 weeks after germination, light intensity increases beyond 0.139 cal. cm^{-2} min^{-1} produced only a small increase in the average net assimilation rates for this cultivar. When light intensities in the order of 0.193 cal. cm^{-2} min^{-1} had been reached no further increases in average net assimilation rate were achieved. The cultivar apparently had reached its light saturation point.

The effect of temperature on the average net assimilation rates of the tomato cultivars under study was not uniform for all three cultivars. On the basis of the data available we can suggest that Burpees Big Boy, the latest cultivar, has a relatively low optimum temperature for average net assimilation, especially at the earlier stages of its development. Five weeks after germination the net assimilation rates at 11 C were 11% higher on the average than the rates obtained at 23 C. Seven weeks after germination a slight reverse was made and the average net assimilation values at 23 C were 1% higher

than the ones obtained at 11 C. This difference is due only to the higher value (8%) obtained at 23 C for the highest light intensity studied (0.289 cal. cm^{-2} min^{-1}) while at lower light intensities the values obtained at 11 C were still higher than the ones obtained at 23 C (7.5% higher at 11 C in both cases).

Rocket, the earliest cultivar, showed the opposite tendency. Five weeks after germination the average net assimilation values observed at 23 C were 10% higher than the ones obtained at 11 C while 7 weeks after germination this tendency had been reversed and the net assimilation rates obtained at 11 C were an average of 10% higher than the ones obtained at 23 C. The only exception in this tendency was found in the readings obtained at the highest light intensity used for this experiment (0.289 cal. cm^{-2} min^{-1}) where the values obtained at 23 C were still 3% higher than those obtained at 11 C.

The response of Early Fireball to different temperatures appears to be more dependent on light intensities than the other two tomato cultivars. While at both dates studied the average net assimilation rates were higher at 23 C than at 11 C the response varied very much between light intensities. Five weeks after germination the net assimilation values obtained at 23 C were 1% higher than those observed at 11 C but this is only on average terms. At a light intensity of 0.139 cal. cm^{-2} min^{-1} the values obtained at 23 C were actually 18% lower than the ones obtained at 11 C. No difference was observed between both temperatures at 0.193 cal. cm^{-2} min^{-1} while at 0.289 cal. cm^{-2} min^{-1} the values obtained at 23 C were 11% higher than the ones obtained at 11 C this last figure being the one that determines a total difference of 1% higher values at 23 C. Seven weeks after germination

the average net assimilation values obtained at 23 C were 8% higher than the ones obtained at 11 C but an actual reverse in the response to light intensities, in relation to temperature, seems to have taken place. At light intensity 0.139 cal. cm^{-2} min^{-1} the values obtained at 23 C were 16% higher than those obtained at 11 C. At a light intensity of 0.193 cal. cm^{-2} min^{-1} there was no difference between the two temperatures studied while at a light intensity of 0.289 cal. cm^{-2} min^{-1} the values obtained at 23 C were 4% lower than the ones obtained at 11 C. This is the opposite trend to the one observed 5 weeks after germination where the highest light intensity showed larger net assimilation rates at 11 C than at 23 C.

On the cabbage experiments no comparisons were possible to determine the effect of age on the cultivars of this species. The light and temperature effects on net assimilation rates for the three cultivars studied seem to be in agreement with the results observed on their tomato counterparts. 5 weeks after germination.

Six weeks after germination, Triple green, as Burpees Big Boy its tomato counterpart for these experiments, appears to have a relatively low optimim temperature at this stage of its development. The average net assimilation rates at 11 C were 22% higher than the values obtained for this cultivar at 23 C.

Sanibel a cultivar the maturity of which lies between the other two, showed an average net assimilation value 16% higher at 23 C than at 11 C. The only exception to this trend were the values found at a light intensity of 0.289 cal. cm^{-2} min^{-1} where the net assimilation rate at 23 C was 13% lower than the one observed at 11 C.

Emerald Acre, the earliest maturing cultivar, showed 6% higher net

assimilation rates at 23 C than the ones observed at 11 C. The exception for this trend were the values found at a light intensity of 0.139 cal. cm^{-2} min^{-1} where the net assimilation rate at 23 C was 74% lower than the one observed at 11 C. Due to the small magnitude of these values (7.8 CO_2 mg g^{-1} hr^{-1} at 11 C and 1.8 CO_2 mg g^{-1} hr^{-1} at 23 C) this high percentage difference might not be as significant as it would appear and its influence in the average trend of the cultivar is not as great as the percentage value would indicate.

The response of all three cultivars to an increase in light intensities was always an increase in net assimilation rates denoting that we had not reached, during this experiment, the light saturation point for any of them.

Sanibel showed the most marked increases in net assimilation rates with increases in the light intensities so that a a light intensity of 0.289 cal. cm^{-2} min^{-1} this cultivar had either reached or surpassed the net assimilation rates of Triple Green which at the other two light intensities used in these experiments had the highest net assimilation rates of the three cabbage cultivars under study. Triple Green showed the slowest increases in net assimilation rates with increases in light intensity and at 23 C it seemed to be close to its light saturation point when the light intensity reached values of 0.289 cal. cm^{-2} min^{-1}

What is the significance of these results and how could they have a bearing on their maturity periods?

The data obtained in these experiments suggest that different cultivars even if they belong to the same species, have different responses to changes in age, light and temperatures. These factors function in a complex relationship. While age can modify the light

saturation points of different cultivars, light intensity can in turn affect their response to different temperatures. This was very obvious in the Early Fireball tomato cultivar where light intensities were the factor determining positive or negative changes in net assimilation rates when the temperature was raised from 11 C to 23 C. Age also influenced these responses and actually reversed the trend of different light intensities to increase or decrease net assimilation rates with an increase in temperature as we can see by comparing the values and percentage changes of Early Fireball net assimilation rates 5 and 7 weeks after germination.

This influence of age and light intensity on response to temperature increases was also observable to a greater or lesser degree in all the other tomato and cabbage cultivars studied during these experiments. These complex responses to the different environmental factors in which we can not really talk of isolated optimum values agrees with Blackman and Meyer reports on this subject (9, 44).

The effect of the relatively low temperature, under the conditions of this study, is particularly interesting in respect to the latest maturing cultivars used for tomatoes and for cabbages. Burpees Big Boy, our latest maturing tomato cultivar and Triple Green, our latest maturing cabbage cultivar seem to perform better, at least during the earlier stages of their development, at lower than at higher temperatures. Seven weeks after germination this trend was no longer apparent in our tomato experiments where both temperatures produced quite similar results. No observation of the effect of age on this trend was possible in our cabbage experiments.

It is also interesting to point out that during the earlier stages

of plant development both Burpees Big Boy and Triple Green appear to be as good or better photosynthesizers than their earlier counterparts, specially at 11 C and, for cabbage, at the lower light intensities studied.

The explanation of this response to temperature changes could be explained by figure 8. This graph relating the effects of temperature on photosynthesis, respiration and net assimilation is similar to the one given by Kramer and Kozlowski for *Pinus cembra* seedlings in their book dealing with the physiology of trees (37).

Five weeks after germination the net assimilation curve of Burpees Big Boy could be similar to the net assimilation curve X. A and A' would be the values found at 11 C and at 23 C respectively. As we can see at 23 C the peak has been exceeded and our net assimilation rates have started to decrease. Point A, being closer to the "optimum" temperature for this cultivar, under the conditions of our study, would show higher net assimilation rates than A' that is slightly further away from this point. It is important to realize however that one (A) has not yet reached this "optimum" value while the other (A') has already surpassed it.

A change in cultivar, light intensity or age could shift the curve along the abscissa. In the case of Burpees Big Boy 7 weeks after germination the net assimilation curve could have shifted slightly to the right to curve Y. B and B' would be the net assimilation rates at 11 C and 23 C respectively. In this case both of them would be practically equidistant of the "optimum" temperature for this curve and practically no difference (1%) could be found between them. The fact that 2 different plants were used in these experiments could be responsible for this

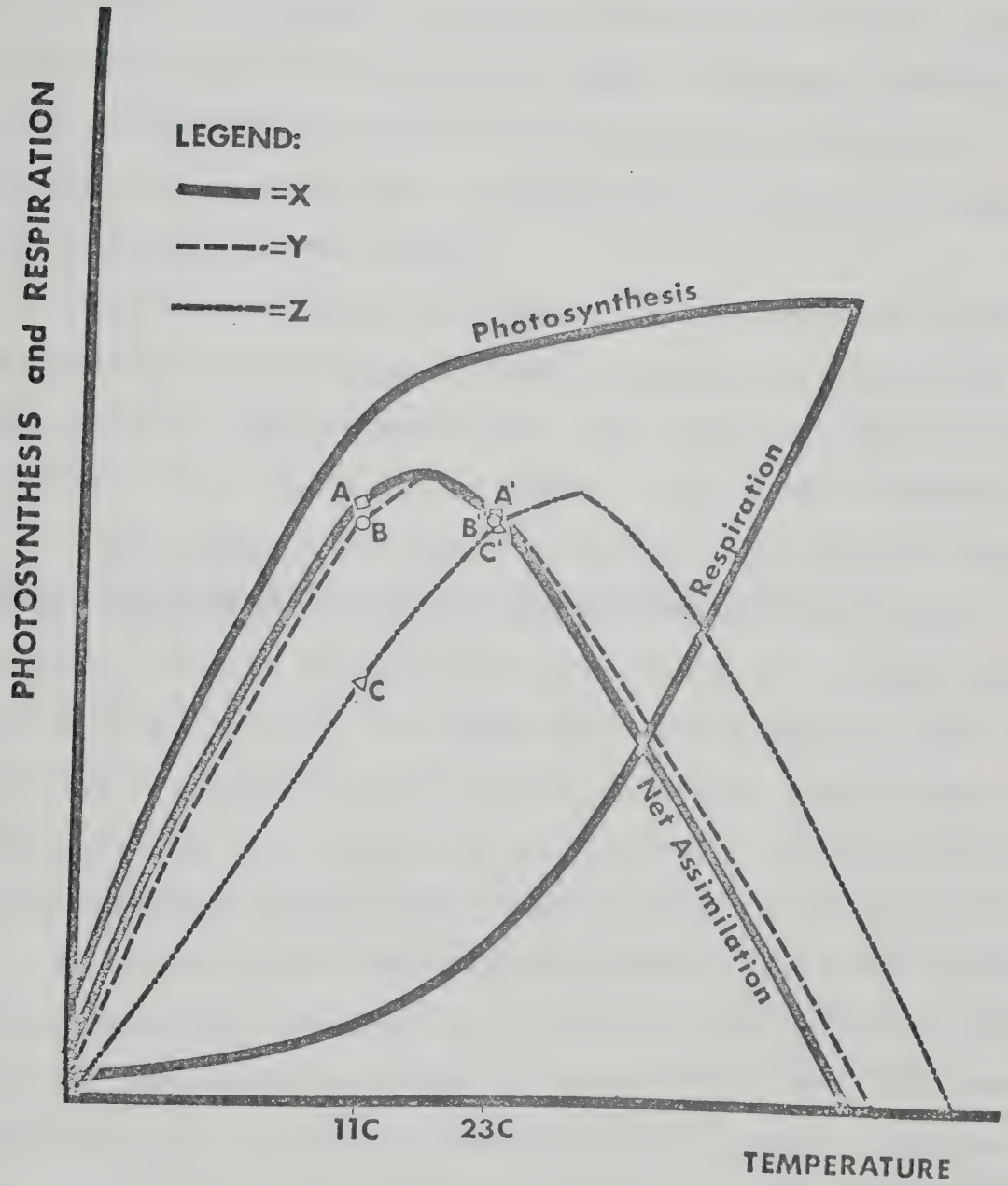

Fig. 8. Hypothetical Photosynthesis, Respiration and Net Assimilation curves.
(See text page 105 for explanation of curves X, Y and Z).

slight change rather than age. Higher temperatures however would decrease the net assimilation rates since the optimum temperature seems to have been surpassed.

In the case of Rocket, our earliest tomato cultivar, the net assimilation curve could be similar to Z and since the "optimum" temperature at the environmental conditions of our experiment, was not reached, increases in temperature would increase the net assimilation rates until this temperature had been reached.

Light intensity changes can have the same shifting effect on the net assimilation curve as age or different cultivars had and change the position of our "optimum" temperature. This seems to have been the case in several of our results and particularly in Early Fireball tomatoes.

If this hypothesis is right it could partially explain why Burpees Big Boy and Triple Green are our latest maturing tomato and cabbage cultivars. Early in the season they can perform as well or better than the earlier cultivars, later in the summer when higher temperatures can be expected there is a marked decrease in the net assimilation rates of these cultivars, while the earlier ones would take advantage of the higher temperatures since they appear to have a higher "optimum" temperature under similar conditions.

Rocket, our earliest tomato cultivar, showed a very marked increase in net assimilation rates with age. In this case the shift in the curve was along the ordinate and similar to the effects of higher light intensity within the same temperature conditions when a shift is the curve also would be in the ordinate axis. This marked increase in net assimilation rates, by far exceeding the values found for Burpees Big Boy or Early Fireball, would be a good explanation of its earliness since it would mean that at this stage Rocket would be able to increase in dry

weight much faster than any of the other two studied.

The reason why Early Fireball is earlier than Burpees Big Boy remains unclear even if our previous hypothesis on the effect of higher temperatures later in the season holds true. Early Fireball net assimilation values were very low during the whole experiment. Possible aclamation effects or other experimental errors might be the cause for Early Fireball showing such a low light saturation point 7 weeks after germination. It is conceivable that Early Fireball could follow a pattern of increasing net assimilation rates similar to Rocket either at this stage or late in the season. It could be however that we will have to look into other factors for this cultivar. Even if its net assimilation rates on the 5th leaf from the top, are lower, the total net assimilation rate for the whole plant might be higher. Factors as anatomical or morphological differences, later senescing leaves or earlier photosynthesizing younger leaves could influence its total net assimilation. It is interesting to point out that Burpees Big Boy has a much more bushy form than Early Fireball and self-shading for most of the photosynthesizing area of this cultivar could put it at a disadvantage in terms of whole plant net assimilation when compared with Early Fireball.

No explanation for the difference in earliness between our cabbage cultivars can be offered on the basis of the data available except for the apparent similarities in their response to temperatures of Burpees Big Boy and Triple Green that were mentioned.

Later in their development marked increases in the net assimilation rates of Sanibel and especially Emerald Acre might be possible as we have observed in the case of Rocket. Higher whole plant net assimilation rates, as has been suggested for Early Fireball, might also be shown by

these cultivars. Further experiments on this subject using a larger scope of temperatures, light intensities, development stages and cultivars should provide a better basis to understand this complex phenomenon of vegetative earliness.

We believe however that these experiments have provided us with some very interesting working hypotheses and have opened several important questions on this subject that will help future researchers to conduct a more detailed analysis of the factors that affect earliness in this species in its relationship with net assimilation.

LITERATURE CITED

1. Ahmetov, G.S. and Bairomov, B.I. 1968. Foliar diagnosis of the nutritional status of the tea plant. Fertilite 30: 65-68. (Horticultural Abstracts 39: 1808).

2. Albaum, H.G. 1952. The metabolism of phosphorylated compounds in plants. Ann. Rev. Plant Physiol. 3: 35-58.

3. Andrew, W.T. 1973. A presentation to the Agricultural products marketing council, Alberta Department of Agriculture. Alberta Department of Agriculture, January 1973. (mimeographed).

4. Arnon, D.I., Stout, P.R. and Sipos, F. 1940. Radioactive phosphorus as an indicator of phosphorus absorption of tomato fruits at various stages of development. Amer. J. Bot. 27: 791-798.

5. Arnon, D.I. and Hoagland, D.R. 1943. Composition of the tomato plant as influenced by nutrient supply in relation to fruiting. Bot. Gaz. 104: 576-590.

6. Baboth, E. 1968. The effect of cobalt ions on the initial development on ^{32}P incorporation in cucurbitaceous plants. Novenytermetes 17: 239-248. (Horticultural Abstracts 39: 2679).

7. Barke, R.E. and Menary, R.C. 1971. Calcium nutrition of the tomato as influenced by total salts and ammonium nutrition. Aust. J. Exp. Agr. and Animal Husbandry 11 (52): 562-569.

8. Bjorkman, O., Pearry, R., Harrison, A.T. and Mooney, H. 1972. Photosynthetic adaptation to high temperature: A field of study in Death Valley, California. Science 175: 786-789.

9. Blackman, F.F. 1905. Optima and limiting factors. Ann. Bot. 19: 281-295.

10. Blatt, C.R. 1968. Response of Acadia strawberry to two forms of three rates of nitrogen at two pH levels. Proc. Amer. Soc. Hort. Sci. 92: 346-353.

11. Bowser, W.E., Kjearsgaard, A.A. and Wells, R.E. 1962. Soil survey of Edmonton sheet (83-4). Univ. Alta. Bull. SS-4, Edmonton, Alberta.

12. Brar, J.S., Nandpuri, K.S. and Uppal, S.S. 1971. Response of tomato varieties to the application of nitrogen and phosphorus in the Kulu valley. J. Res., Ludhiana, India 8 (1): 29-32. (Horticultural Abstracts 42: 11057).

13. Brooking, I.R. and Taylor, A.O. 1973. Plants under climatic stress V: Chilling and light effects on radiocarbon exchange between photosynthetic intermediates of soybean. Plant Physiol. 52(2): 180-182.

14. Brayer, T.C. and Stout, P.R. 1959. The macronutrient elements. Ann. Rev. Plant Physiol. 10: 277-300. (Ekdahl, I. 1957. Kgl. Lantbruks Hogskol. Ann. 23: 497-518).

15. Burkhart, L. and Collins, E.R. 1941. Mineral nutrients in peanut plant growth. Proc. Soil. Sci. Soc. Amer. 6: 272-280.

16. Cathey, H.M. 1964. Physiology of growth retarding chemicals. Ann. Rev. Plant Physiol. 15: 271-302.

17. Carter, O.G. and Lathwell, D.J. 1967. Effects of Temperature on orthophosphate absorption by excised corn roots. Plant Physiol. 42: 1407-1412.

18. Cooil, B.J., Watanabe, Y. and Nakata, S. 1966. Relationships of phosphorus supply to growth yields and leaf compositon in macadamia. Hawaii Agr. Exp. Sta. Tech. Bull. 1966: 71.

19. Cornforth, I.S. 1968. Relationships between soil volume used by roots and nutrient accessibility. J. Soil Sc. 19: 291-301.

20. Cutcliffe, J.A., Munro, D. and MacKay, D.C. 1968. Effects of nitrogen, phosphorus, potassium and manure on terminal, lateral and total yields and maturity of broccoli. Can. J. Plant Sci. 48: 439-446.

21. Evans, H.J. and Sorger, G.J. 1966. Mineral nutrition. Annu. Rev. Plant Physiol. 17: 47-76.

22. Farquhar, R.H. 1967. The interpretation and use of tissue analysis within a fertilizer advisory service for sugarcane in North Queensland. Proc. 12th Congr. Int. Soc. Sugarcane Technol., Puerto Rico. 1965, 1967: 227-236. (Horticultural Abstracts 39: 3930.)

23. Fedorov, N.I. and Egorova, S.I. 1963. The effect of growth stimulators on phosphorus and calcium uptake by woody plants. Soviet Plant Physiol. 10: 180-182.

24. Fordham, R. 1972. Observations on the growth of root and shoots of tea (*Camelia sinensis* L.) in South Malawi. J. Hort. Sci. 47(2): 221-229.

25. Freeland, R.O. 1944. Apparent photosynthesis in some conifers during winter. Plant Physiol. 19: 179-185.

26. G , L. 1967. The mineral fertilizing of tomato. Progr. Agric., Bologna 13: 328-329. (Horticultural Abstracts 37: 7153.)

27. Gilbert, F.A. 1948. Mineral nutrition in plants and animals. Amer. Petroleum Inst. Univ. of Oklahoma, p. 19-20.

28. Harris, F.S. 1914. The effect of soil moisture, plant food and age on the ratio of tops to roots in plants. J. Amer. Soc. Agron. 6: 65-75.

29. Hegwood, D.A. 1972. Effects of soil calcium level on mineral concentrations in limabeans seedlings. J. Amer. Soc. Hort. Sci. 97(2): 232-235.

30. Hernando, V., Sanchez Conde, P. and Azuara del Molino, C. 1966. Variation in the pH and mineral content of tomato sap resulting from treatments with different levels of nitrogen and calcium. Ann. Edaf. Agrobiol. 25: 571-587. (Horticultural Abstracts 37: 7158.)

31. Hew, C.S. and Krotkov, G. 1967. Effect of temperature on apparent photosynthesis carbon dioxide evolution in light and darkness by attached leaves of sunflower, soyabean and eggplant. Plant Physiol. 42(Suppl.): 47 (abstract only.)

32. Horada, T., Takaki, H. and Yamada, Y. 1968. Effect of nitrogen sources on the chemical components of young plants. Soil Sci. Plant Nutrition 14: 47-55.

33. Howell, R.W. 1954. Phosphorus nutrition of soyabeans. Plant Physiol. 29: 477-483.

34. Humphries, E.C. and Maciejewska-Potapezyk. 1960. Effects of I.A.A., N.A.A. and kinetin on phosphorus fractions in hypocotyls of dwarf beans (*Phaseolus vulgaris*). Ann. Bot. 24: 311-316.

35. Ismail, Z., Habeeb, H. and El-Wakeel, A.T. 1967. The use of soil test for assessing the phosphorus and potassium status of the grapevine. Agr. Res. Rev., Cairo 45(3): 18-26. (Horticultural Abstracts 39: 432.)

36. Khuspe, V.S. and Kalke, S.D. 1968. Growth and yield of cabbage (*Brassica oleracea* var. *capitata* L.) as influenced by the application of nitrophosphate and amonium sulphate and superphosphate combined. Poona Agr. Coll. Mag. 58(2/3): 26-32. (Horticultural Abstracts 39: 4676.)

37. Kramer, P.J., and Kozlowski, T.T. 1960. Physiology of trees. McGraw-Hill Book Co., Inc., New York. p. 82.

38. Lin, C.F. 1966. Diagnosis of the phosphorus fertilizer requirements of the tea plant. Soils and Fertilizers, Taiwan 1965, 1966: 64-69. (Tropical Abstracts 23: 1929.)

39. Marre, E. 1961. Phosphorylation in higher plants. Ann. Rev. Plant Physiol. 12: 195-218.

40. Mascarenhas, H.A. and others. 1967. Responses of beans to fertilizing with nitrogen, phosphorus and potassium on organic soil in the Ribeirao Preto area. Bragantia 26 (Supplement): V-VIII. (Horticultural Abstracts 39: 4770.)

41. Mayo, J.M. 1971. Lab Manual, Botany 320. Univ. of Alberta, Edmonton, Alberta. pp. 9.

42. Mayo, J.M., Despain, D.G. and Van Zinderen Bakker, Jr., E.M. 1972. CO_2 assimilation by *Dryas integrifolia* on Devon Island, Northwest Territories. Can. J. Bot. 51(3): 581-588.

43. McEvoy, E.T. 1965. Carbon dioxide concentration affects uptake of phosphorus by chrysanthemums, geraniums and cucumber plants. Can. Hort. Council Res. Comm. Rept. p.6.

44. Meyer, B.S. and Anderson, D.B. 1958. Plant physiology. D. Van Nostrand Co. (Canada) Ltd., Toronto, Canada.

45. Millikan, C.R., Bjarnason, E.N., Osborn, R.K. and Hayer, B.C. 1971. Calcium concentration in tomato fruit in relation to the incidence of Blossom End Rot. Aust. J. Exp. Agr. and Animal Husbandry 11(52): 570-572.

46. Muira, Y. 1968. Studies on the manuring of *Cyclamen persicum* (i) Effects of nitrogen, phosphorus, potassium and calcium on growth. Bull. Kanagawa Hort. Exp. Sta. 16: 79-89. (Horticultural Abstracts 40: 1608.)

47. Molnar, S.A. 1969. Evaluation of pH, total sugars and relative amounts of malate and citrate as criteria for earliness in tomato. M.Sc. Thesis, Univ. of Alberta, Edmonton, Alberta.

48. Neales, T.F. and Incoll, L.D. 1968. The control of leaf photosynthesis rate by the level of assimilate concentration in the leaf: A review of the hypothesis. Bot. Rev. 34(2): 107-124.

49. Okamoto, G. and Kobayashi, A. 1971. Effects of shoot pinching and boron sprays on nutrient content and berry set in Muscat of Alexandria vines II. J. Jap. Soc. Hort. Sci. 40(3): 212-224. (Horticultural Abstracts 42: 5753.)

50. Oprea, D. 1968. Morphological and anatomical changes in the grape vine induced by the nutritional level. Lucr. sti Inst. Agron. N. Balceseu, Ser. B. 11: 263-273. (Horticultural Abstracts 39: 2363.)

51. Ormrod, D.P. and Williams, W.A. 1960. Phosphorus metabolism of *Trifolium hirtum* as affected by 2,4-D and giberellic acid. Plant Physiol. 35: 81-87.

52. Pandita, M.L. 1966. Some aspects of the physiology of earliness in

vegetable crops. M.Sc. Thesis, Univ. of Alberta, Edmonton, Alta.

53. Pandita, M.L. and Andrew, W.T. 1967. A correlation between phosphorus content of leaf tissue and days to maturity in tomato and lettuce. Proc. Amer. Soc. Hort. Sci. 91: 544-549.

54. Parkash, V. and Bhardwaj, S.N. 1965. Influence of foliar application of molibdenum and cobalt on growth of cabbage. Indian J. Hort. 22: 349-350. (Horticultural Abstracts 37: 2802.)

55. Poison, A. 1955. Mineral stoffe und photosynthese. Encyclopedia Plant Physiol. 4: 354-380.)

56. Poovaiah, B.W. and Leopold, A.C. 1973. Diferral of leaf senescence with calcium. Plant Physiol. 52: 236-239.

57. Rehfeld, D.W. and Jensen, R.G. 1973. Metabolism of separated leaf cells III: Effects of calcium and NH_4 on product distribution during photosynthesis with cotton cells. Plant Physiol. 52: 17-22.

58. Resnick and Flowers, 1971. The effect of low osmotic potential on phosphate uptake and metabolism in beet roots. Ann. Bot. 35(143): 1179-1189.

59. Roach, A.G. 1966. Application of Technicon Auto-Analyzer equipment to the routine determination of calcium and phosphorus in animal feed stuffs. Technicon Controls Inc., 65-P8 4E: 137-140. Ardsly (Chauncey), N.Y.

60. Roberts, A.N. and Kenworthy, A.L. 1956. Growth and composition of the strawberry plant in relation to root temperature and intensity of nutrition. Proc. Amer. Soc. Hort. Sci. 68: 157-168.

61. Roberts, R.H. and Struckmeyer, B.E. 1946. The effect of top environment and flowering upon top-root ratios. Plant Physiol. 21: 332-344.

62. Saitoh, H. 1971. Calcium transport in tomato plants supplied with different levels of calcium. Hirosaki Univ. Fac. Agr. Bull. 17: 40-49. (Horticultural Abstracts 42: 4061.)

63. Salisbury, F.B. and Ross, C. 1969. Plant physiology. Wadsworth Pub. Co. Inc. Belmont, Cal.

64. Sivasubramaniam, S. and Talibudeen, O. 1971. Effect of aluminum on growth of tea *(Camelia sinensis)* and its uptake of potassium and phosphorus. J. of the Sc. of Food and Agr. U.K. 22(7): 325-329.

65. Smith, P.F. 1962. Mineral analysis of plant tissues. Annu. Rev. Plant Physiol. 13: 81-108.

66. Sommer, A.L. 1936. The relationship of the phosphate concentration of solution culture to the type and size of root system and the time of maturity of certain plants. J. Agr. Res. 52: 133-148.

67. Sorokin, H. and Sommer, A.L. 1940. Effect of calcium defficiency upon the roots of *Pisum sativum*. Amer. J. Bot. 27: 308-318.

68. Srivastava, S.C. and Agrawal, M.P. 1968. Nitrogen and phosphorus interrelationship in the fertilization of sugarcane in some northern indian soils. J. Ind. Soc. Soil Sci. 16: 161-165. (Tropical Abstracts 24: 424.)

69. Street, H.E. 1966. The physiology of root growth. Annu. Rev. Plant Physiol. 17: 315-334.

70. Talling, J.F. 1961. Photosynthesis under natural conditions. Annu. Rev. Plant Physiol. 12: 133-154.

71. Tatsumi, M. and Kageyama, M. 1964. Studies on cultural practices in nursery bed. II. Further observations on the quality of tomato seedlings. Bull. Hort. Res. Sta., Horatsuka Ser. A. 3: 133-160. (Horticultural Abstracts 37: 7148.)

72. Taylor, A.O. and Pawley, J.A. 1971. Plants under climatic stress. I. Low temperature, high light effects on photosynthesis. Plant Physiol. 47: 713-718.

73. Terry, N. and Ulrich, A. 1973. Effects of phosphorus defficiency on the photosynthesis and respiration of leaves of sugar beet. Plant Physiol. 51: 43-47.

74. Thorup, R.M. 1969. Root development and phosphorus uptake by tomato plants under controlled soil moisture conditions. Agron. J. 61: 808-811.

75. Tisdale, S.L. and Nelson, W. 1969. Soil fertility and fertilizers. Macmillan Co., Cother-Macmillan Co. Ltd., Toronto, Ont.

76. Turner, T.W. 1922. Studies of the mechanism of the physiological effects of certain mineral salts in altering the ratio of top growth to root growth in seed plants. Amer. J. Bot. 9: 415-445.

77. Ulrich, A., Rirse, D., Hills, F.J., George, A.G. and Morse, M.D. 1959. Plant analysis - A guide for sugar beet fertilization. California Agr. Exp. Sta. Bull. 1959: 766.

78. Upmeyer, D.J. and Koller, H.R. 1973. Diurnal trends in net photosynthetic rate and carbohydrate levels of soyabean leaves. Plant Physiol. 51: 871-874.

79. Van der Post, C.J. and Van der Meys, M.Q. 1968. The relationship of root growth to crop development in some glasshouse grown vegetables. Meded Dir Tiunb. 31: 447-452.

80. Wallace, A. 1966. Current topics in plant nutrition. Edwards Bros. Inc., Ann. Arbor, Mich.

81. Ward, G.M. 1963. The application of tissue analysis to greenhouse tomato mutrition. Proc. Amer. Soc. Hort. Sci. 83: 695-699.

82. Webster, G.C. 1961. Protein synthesis. Annu. Rev. Plant Physiol. 12: 113-132.

83. Willstatter, R. and Stoll, A. 1918. Untersuchingen uber die assimilation der kohlensaure. Julius Springer, Berlin.

84. Wilson, A.M. and Huffaker, R.C. 1964. Effect of moisture stress on acid soluble phosphorus compounds in *Trifolium subterraneum*. Plant Physiol. 39: 555-560.

85. Yuda, E. and Okamoto, S. 1968. The effect of soil reaction on the growth of young citrus plants. III. Level of phosphorus application. J. Jap. Soc. Hort. Sci. 37: 45-50. (Horticultural 39: 1428).

APPENDIX ONE

Chemical Ingredients for the U.C. Soil Mixture used in these experiments (50 Per Cent Fine Sand, 50 Per Cent Peat Moss)

Amount of materials to be added to each cubic yard:

120 g Potassium nitrate

120 g Potassium sulphate

1125 g Superphosphate

800 g Calcium carbonate

600 g Magnesium carbonate

42 g Hoof and Horn

Analysis of the mixture in ppm:

N	P	K	Ca	S	Sol. Salts	pH
9	19	29	150	150	1.1	6.4